Automotive

ADAS

Camera Systems

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Contents

1. Introduction

Advance Driver Assistance Systems (ADAS) is one of the key megatrends in the automotive industry. Initially introduced as optional add-ons in the luxury segment, these systems are part of standard configurations in virtually every new vehicle in production. As the name suggests, these systems aid the driver in different driving tasks, enhancing the safety and comfort of the driving experience.

Sensors are an integral part of ADAS. They obtain information about the vehicle's surroundings and deliver it to the processing and control units, where automated decisions are made and resulting actions are performed. Currently, ADAS employs multiple sensors, including cameras, radar, lidar, and ultrasonic sensors. Different functions will utilise one or more types of sensors, depending on the required information (Fig. 1).

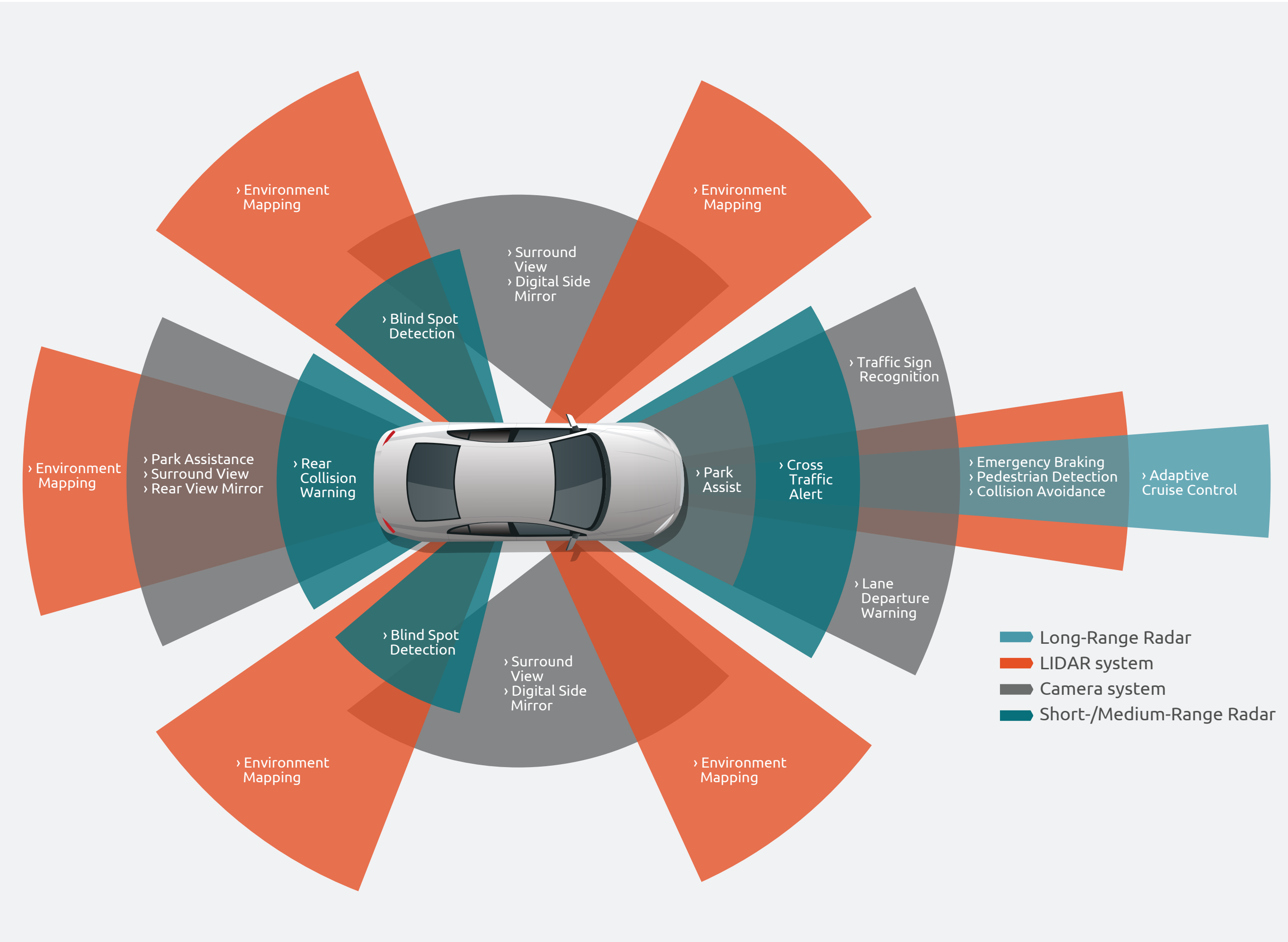


Fig. 1 ADAS sensors, their function and sensitivity field

2. ADAS camera sensors – description and trends

Camera sensors are widely used in today's vehicles. These can be front facing, rear, side and surround view and in-cabin cameras for driver and passenger monitoring to aid drivers and enable autonomous driving.

For aiding partial or full autonomous driving systems, cameras ideally complement each other with radars as they are both essential for obtaining even low levels of autonomy. For higher levels of autonomy, other types of sensors need to be employed as well, such as lidars. As suggested by Fig. 2, cameras have the best answer to some of the key requirements for an autonomous driving system. They provide higher angular resolution and are good at detecting the edge of objects. They excel in the ability to recognise traffic signs and detect lanes. They are also the only ADAS sensor that can recognize colours. All this comes with the most mature technology and therefore low costs as well.

The parity of cameras and radars becomes obvious from Fig. 2, as the radar excels in the requirements that cameras lag in. These drawbacks relate to sensing the depth and performance in adverse weather and low light performance.

Key requirements	Camera	Radar	Lidar
Angular Resolution	● Superior	● Average	● Superior
Traffic Signs	● Superior	● Inferior	● Average
Object Edge Precision	● Superior	● Inferior	● Superior
Lane Detection	● Superior	● Inferior	● Average
Color Recognition	● Superior	● Inferior	● Inferior
Cost	● Superior	● Superior	● Average
Depth Resolution	● Average	● Superior	● Superior
Depth Range	● Average	● Superior	● Superior
Adverse Weather	● Average	● Superior	● Average
Low-light performance	● Average	● Superior	● Superior
Velocity	● Inferior	● Superior	● Average
Automation Level	L0, L1, L2	L0, L1, L2	L2, L3, L4, L5

● Superior ● Average ● Inferior

Fig. 2 ADAS sensor functional comparison

2.1 Application description

Camera sensors can be categorized into five main types:

› Front vision:

The cameras in the front of the vehicles serve to detect objects in the front vision field, Fig. 3. They can generally have one, two or three camera sensors within them to get better focus of objects at different distances. These cameras are typically used to enable features like lane departure warning (LKW), Adaptive Cruise Control (ACC), Collision Avoidance, Traffic Sign Recognition (TSR) and High Beam Control (HBC) by detection lane markings, vehicles and objects.

› Surround view:

These cameras are used for creating the 360° view around the vehicles. They are of lower resolution, but the image processing requirements are increased as the sensing of at least four cameras need to be combined to create a coherent surround view of the vehicle. There are instances where the vehicles only have side view cameras and/or rear-view cameras which although doesn't offer the full 360° view but enables functionalities like blind spot detection (BSD), lane change assistance (LCA), park assistance (PA), etc.

› Night vision

These cameras use infrared (IR) thermal imaging to detect objects, animals and pedestrians which are difficult to detect with a naked eye at night. These are also being used more extensively by luxury car models, with indication of the technology trickling down to regular vehicles as well.

› Driver/occupant monitoring systems (DMS/OMS):

An emerging trend in cameras is also one that is turned inside the cabin to monitor the driver and occupants of the vehicle. Some of these systems can detect if the seatbelts are worn and if the driver is drowsy. The potential behind such cameras extends to increasing safety by adjusting seatbelts and airbag deployment in the moment of a crash, increasing occupants' comfort by adjusting air conditioning settings based on the positions of occupants, they enable gesture-controlled infotainment systems and detect harmful behaviour of passengers of future autonomous vehicles. The in-cabin cameras rely heavily on Artificial Intelligence (AI) in analysing the video data obtained.

› Mirror replacement:

To date the mirror replacement cameras are being adopted by luxury car models. They enhance visibility by providing a wider view to the driver, improve the vehicles aerodynamics and improve performance in adverse conditions as they are less affected by rain, snow and fog, can have night vision and anti-glare functionalities. Additionally, they can add information to the ADAS system by warning of lane departures and indicate distance to objects.

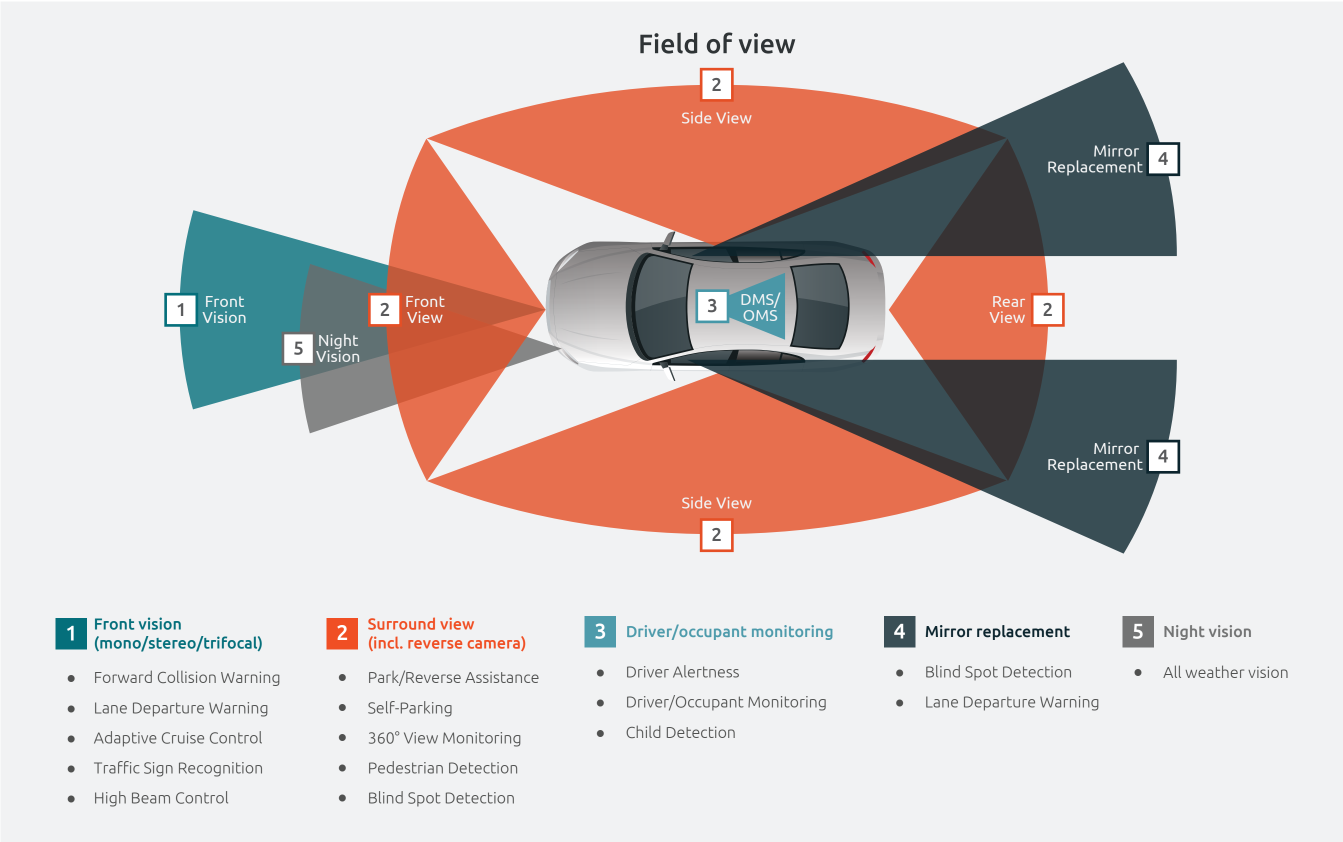


Fig. 3 Main camera systems overview

2.2 Application trends

› Higher resolution:

As can be seen from Fig. 4, automotive cameras can have a range of resolutions ranging from sub mega pixel to over 8MP at front vision cameras and surround view cameras. In the past, bulk of the cameras used were at the lower end of this spectrum, but trends show a tendency to go to the higher resolution UHD area. Front Vision cameras are rapidly moving towards 8 MP range whereas the Surround View Cameras are more trending towards the 3 MP range.

› Increased field of view (FOV):

There is increasing design demand for cameras with wider FOVs to capture more of vehicle's surroundings. On top, there are advanced camera systems being deployed which are incorporating adaptive FOV technology that allows the camera to adjust its FOV based on driving conditions. For example, the camera might use a narrower FOV for long-distance detection on highways and a wider FOV for city driving or parking.

› High dynamic range (HDR):

Automotive cameras require high dynamic range. This usually means using different sensors with different lenses for detecting objects in various ranges. The approach of using more camera sensors might even be employed for rear cameras too.

› LED flicker mitigation (LFM):

Vehicles equipped with LED lights and other light sources such as traffic lights and sign boards, equipped with LEDs, may make it difficult to detect objects. LFM functionality solves this problem by capturing images accurately despite having strong LED lights in the scene.

› Low latency:

With the increasing resolution and increasing frame rate the requirement for faster communication protocols is prominent. An overview of the information protocols used in some of the cameras can be seen in the table below.

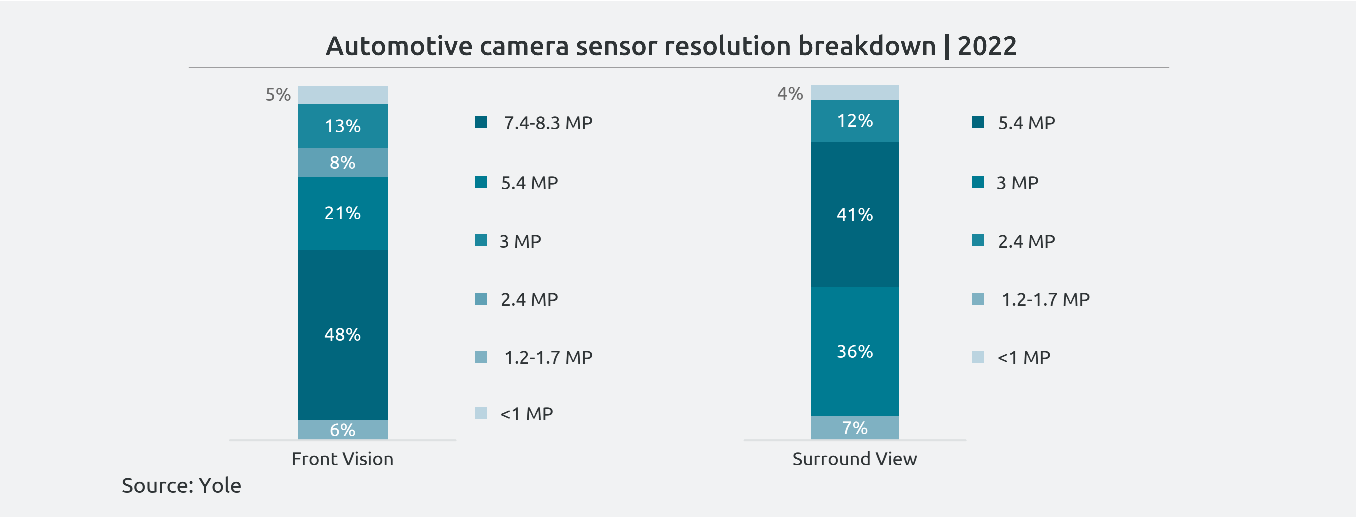


Fig. 4 Automotive Camera Sensor Resolution Breakdown, Source: Imaging for Automotive 2023 report, Yole Intelligence

Requirements	Front vision	Surround view	DMS / OMS
Resolution	8 MP	3 MP	2-5 MP
High Dynamic Range (HDR)	≥120 dB	120 dB	
Field of View (FOV)	30° - 120°	190°	90° - 160°
Interface	SerDes, CAN FD, Ethernet	SerDes, Ethernet, MIPI	CAN FD, FlexRay

Fig. 5 Automotive Trends Overview

As the cameras are exposed to the outside weather conditions, they also need to be able to withstand harsh weather conditions, including extreme temperature variations, moisture and dust. This necessitates an increasing standard of reliability of these sensors.

3. Functional block diagram

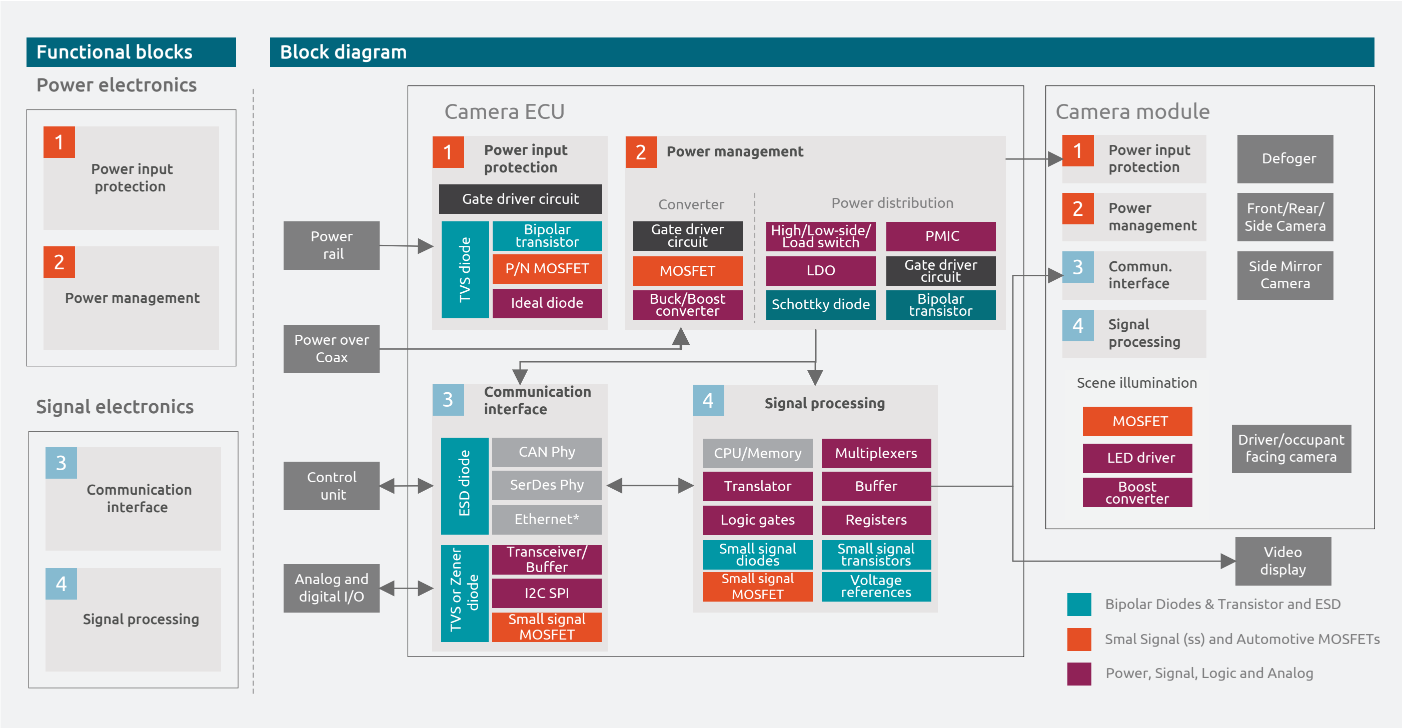


Fig. 6 Automotive Camera internal electronics block diagram

The block diagram in Fig. 6 above gives an overview of the devices that feature in a camera system. The cameras themselves can be directly attached to the camera ECU (Driver/Occupant facing camera) or can have a smaller camera module that is separate from the main Camera ECU. In this case the image capturing is done by the Camera module but the image processing is executed in the main Camera ECU. As is the case with most applications, the functional blocks within can be divided into power handling and information handling blocks. Both have outward-facing interface sections.

1 The **Power Input Protection** block connects the camera to the vehicle's supply network, which can be powered by either the battery or a DC/DC converter. Its main function is to protect the camera from external disturbances and limit power consumption when the camera is not used.

2 The **Power Management** block contains the means for transforming the incoming voltage to a level that is suitable for the rest of the components. This is achieved via switching buck and boost converters in integrated circuits but can also be designed via discrete MOSFETs and Schottky diodes. LDOs then refine these voltages further making them smoother and usable for the fine electronics components like processors. Smart switches can limit the power towards circuits that are not used at a given time, like the cameras themselves, video displays or defoggers. Other circuits like voltage monitoring or wake-up circuits can be realised by small signal MOSFETs, BJTs and diodes to avoid dependence on the processor functionality.

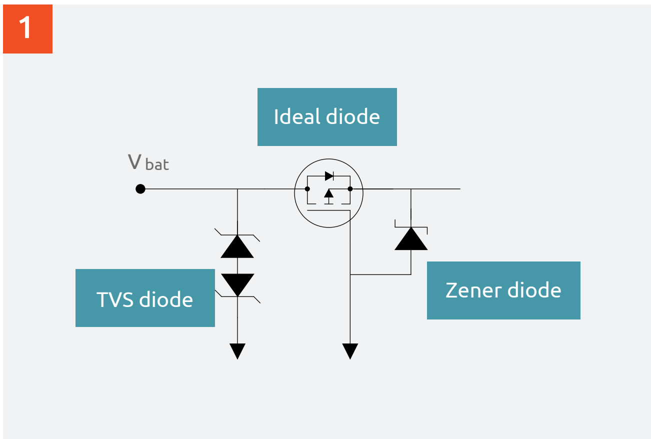
3 The **Communication Interface** block consists of fast CAN or Ethernet PHYs and the accompanying ESD to ensure reliable communication with the controlling unit. Communication protocols adopted by different consortiums of different automotive manufacturers are also formed in this block. Invariably they need the ESD protection that is appropriate to their communication speed and typical line resistances.

4 Finally, the **Signal Processing** block contains the MCU and Memory blocks. Logic devices and small signal devices can implement accompanying logic, interfacing with established blocks, and additional safety layers or increasing GPIO count of the MCU.

In the following chapter the design challenges and the path to their solutions for the four blocks from the diagram above are discussed in detail.

4. Application design challenges and solutions

4.1 Power input protection



Design challenge #1:

Protecting camera system electronics from surges and disturbances on the power signal lines.

Nexperia discrete solution to challenge #1:

For a vehicle's board net of 12 V, ISO7637-2 and ISO16750-2 describe various pulses and conditions that must be considered. These requirements are designed to check for ECU compliance in general. However, transient pulse tests like ISO7637-2 Pulses 1, 2a, 2b, 3a, 3b, 5b and ISO16750-2 §4.6.4 (load dump) are often applied to single TVS devices. These pulses can be negative as well as positive. See our interactive application note IAN50007 for ISO pulse simulations on MOSFET devices.

TVS diodes protect power and signal lines from voltage surges. They have a high protection capability; however, their high capacitance makes them suitable for protecting data lines with low data rates, analog signals and power connections.

When choosing a TVS protection strategy, there are three essential parameters to consider.

- High robustness of the protection device itself against ESD and surge events.
- Low clamping voltage
- Low dynamic resistance - for a steep I-V curve of the protection so that clamping voltage does not increase much if the surge current is increased.

Suggested Nexperia TVS portfolio

Package	Voltage	10/1000µs Power rating
SOD123W	3.5 – 64 V	400 W
SOD128	3.5 – 64 V	600 W

- Small plastic packages with very low height
- Up to 50% board space saving compared to SMA/SMB
- Wide range of voltage choices from 3.3 to 64 V
- Automotive qualified up to junction temperature of 185 °C

For camera modules, separated from the main camera ECUs and supplied by lower voltages, Nexperia offers ultra compact TVS diodes in DFN1006-2 package: PTVS4V5D1BL-Q and PTVS5V5D1BL-Q.

Suggested Nexperia TVS devices: PTVS4V5D1BL-Q and PTVS5V5D1BL-Q

- Bidirectional ESD protection of one line
- Very high surge robustness; I_{PP} up to 40 A for 8/20 µs pulse
- Very low clamping voltage: V_{CL}= 10.3 V typ. for 34 A, 8/20 µs pulse
- ESD protection up to 30 kV
- Very low dynamical resistance R_{dyn} = 0.1 Ohm (TLP)
- Qualified according to AEC-Q101 and recommended for use in automotive applications

Design challenge #2:

Protecting the camera electronics from negative overvoltages that can happen if the battery is connected in reverse.

Nexperia discrete Solution #1 for design challenge #2

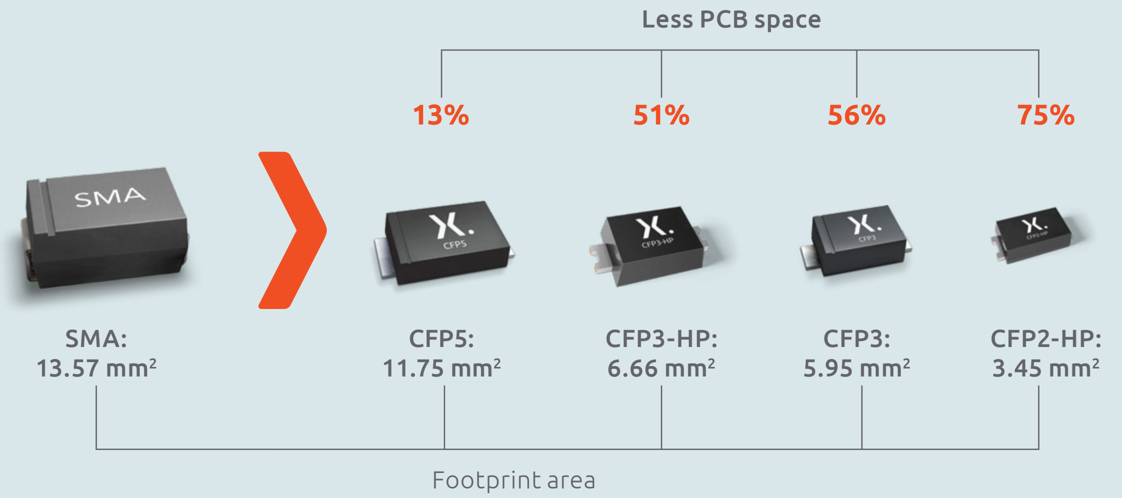
To protect from these, an additional switch can be added. The realization of the switch can be with a diode, Schottky diode, single N-channel MOSFETs or a P-channel MOSFET [AN50001]. Specifically for small power applications, such as Camera, these devices need to be of a small footprint and their resistance should be as low as possible to avoid significant conduction losses within the device. Considering the low power requirements of the camera application, the switch is predominantly realized with a single Schottky diode. The advantage of this approach is easy design-in and low cost. The downsides of the solution, of a voltage drop across the device causing significant losses, can be neglected due to the low power consumption of cameras.

In general, the decision on what device should be employed depends on how much it will heat up. Initial simulations and estimates can provide a ballpark figure, but experimental measurements are there to ensure the design is valid. A suggested measurement method has been proposed in Nexperia Technical Note TN90007 . Even for the initial simulations, the designer needs information about the thermal resistance of the medium the device is connected to. These can also be measured via the virtual junction measurement method of TN90007.

Nexperia offers Schottky diode technology with very low forward drop voltage. The Clip-bonded FlatPower (CFP) packages the devices are offered in enable miniaturization, and the copper clip employed ensures good thermal conductivity towards the PCB. This, in turn, ensures a large surge in current capability and high board-level reliability of the devices.

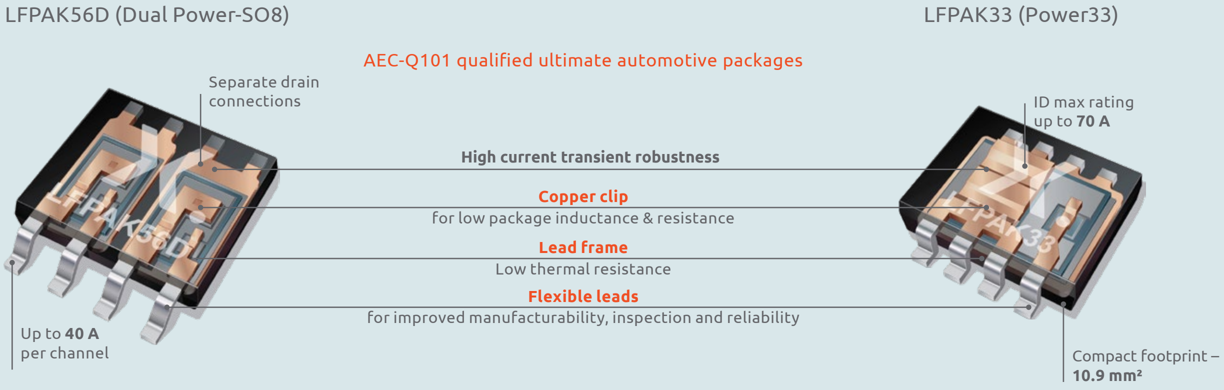
For more information on power diodes and their applications as well as the benefits of the CFP packages, have a look at Nexperias Power Rectifier webinars.

Suggested Nexperia Schottky diodes



- Solid copper clip for high thermal performance and power dissipation
- Reduced package inductance for improved switching behaviour
- High reliability (2 x AEC-Q101, Board Level Reliability compliance)
- Free from delamination
- Junction temperature up to 175 °C
- Small, thin and light design

Suggested Nexperia leaded MOSFETs

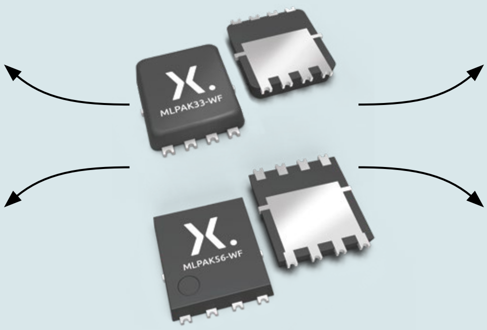


Recommended MOSFET packages for load switches as well as dc/dc converters (see Power Management section) are Nexperia's range of LFPAK33 (3x3 mm leaded, copper clip) and LFPAK56D (5x6 mm dual, leaded, copper clip) packages and the newly introduced MLPAK33 (3x3 mm micro-leaded) and MLPAK56 (5x6 mm micro-leaded) packages. The dual packages can be convenient in case back-to-back protection is required, incorporating both reverse polarity protection and load switch in the same package. For even smaller designs, DFN2020MD-6 (2x2 mm leadless) packages can be considered because of their good thermal performance. All these packages have a copper frame that allows for a good heat transfer from the device die to the PCB, yielding high gains in the thermal performance of the devices as shown in Application Note AN90003. This further opens the possibilities of cooling the device via copper plating of the PCB or just providing high copper content in all the PCB layers to allow for better heat distribution across the PCB and, thus, better heat convection and radiation into the environment [AN50019]. Nexperia's precision electrothermal models allow for making thermal considerations easier AN90034 . The packages with 'gull wing' leads are exceptional for environments that have high temperature oscillations to achieve high board-level reliability. As cameras can be mounted externally, they might be subject to extreme ambient temperatures. All of the packages discussed allow for automatic optical inspection, which is enabled by the side wettable flanks (SWF) in the case of the micro-leaded and leadless package types. A comprehensive guide to MOSFETs can be found in the Nexperia MOSFET handbook.

Suggested Nexperia micro-leaded MOSFETs

Automotive quality
- Automotive Qualified to AEC-Q101 standard

System level savings
- Ultra compact footprint
  - MLPAK33-WF = 10.9 mm²
  - MLPAK56-WF = 31.9 mm²
- Footprint compatible with industry standard packages



High manufactoring reliability
- Micro-leaded design
- Side wettable flanks for Automated Optical Inspection (AOI)

High power density
- Low $R_{DS(on)}$
  - ≥ 1 mΩ in MLPAK56-WF
  - ≥ 2 mΩ in MLPAK33-WF
- High current capability
  - I_D max < 71 A
- Low thermal resistance
  - $R_{th(j-mb)}$ max > 1.54 K/W for MLPAK56-WF
  - $R_{th(j-mb)}$ max > 2.5 K/W for MLPAK33-WF

The packages with 'gull wing' leads are exceptional for environments that have high-temperature oscillations to achieve high board-level reliability. The packages with micro-leads also exhibit good board level reliability. A PCB solder joint evaluation has been caried out through simulating the solder pad creep strain. Fig. 8 below shows the solder area of interest in the evaluation, as well as the simulation results. The simulations indicate that LFPAK33 can last about 2.7 time longer, while MLPAK can last about 1.6 times longer than PQFN leadless packages before the solder joint fails.

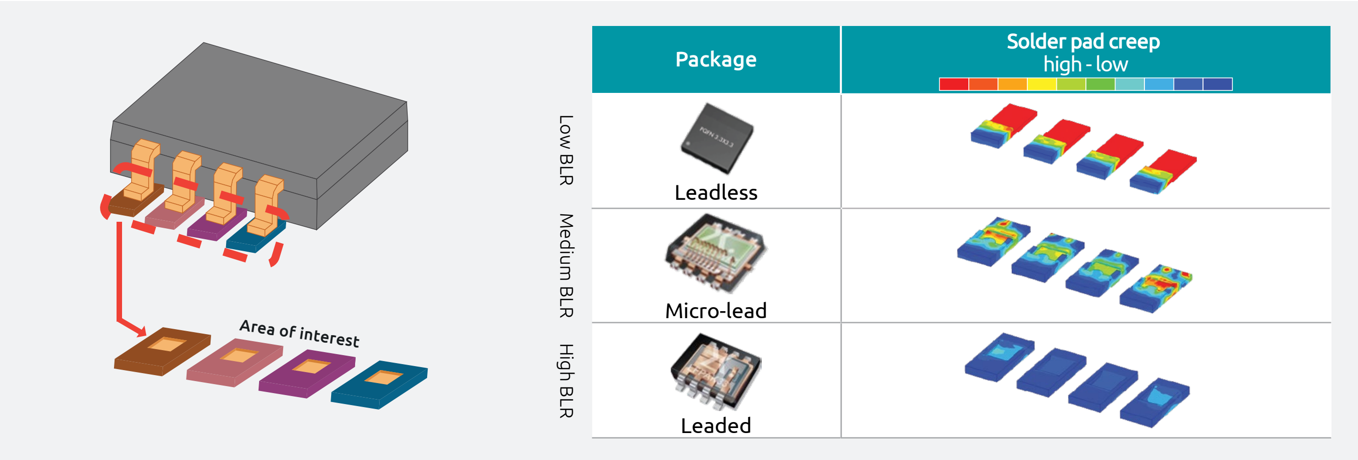
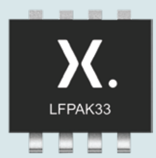


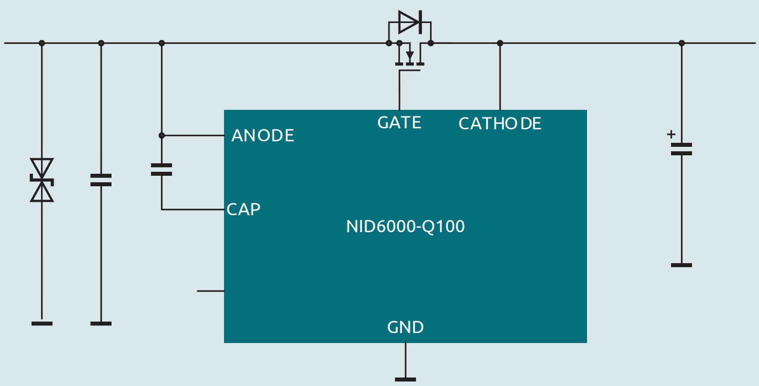
Fig. 8 3x3mm packages solder pad creep strain comparison

In case the supply structure of the vehicle is 48 V, Nexperia offers a range of 80 V and 100 V devices in small packages that have a good conduction and switching performance as well:

V_{DS}	 LFPAK56D/ HB	 LFPAK56D/ HB	 LFPAK56D/ HB	 LFPAK56D/ HB
80 V	12-49 mΩ	12-48 mΩ	14-45 mΩ	81-230 mΩ
100 V	24-134 mΩ	34-156 mΩ	16-50 mΩ	385 mΩ

For controlling the N-channel MOSFETs ideal diode controllers can be used. The controllers ease the design in process of a discrete circuit and have added functionality. The precision of these controllers provides the possibility to rely on their protection without designing in the tolerances of the discrete counterparts. They also control the devices to a precise voltage drop (they are not fully on) maintaining the operating point on the knee of the device output characteristics for very rapid transition to a blocking state in case of need.

Suggested Nexperia Ideal Diode Controller: NID6000-Q100



- Automotive AEC-Q100 Qualified
- Operating Supply 3.2 V – 65 V, for 12 V and 24 V applications
- 20 mV regulated Anode to Cathode forward voltage drop
- 2.3 A peak gate turnoff current
- Reverse Current Blocking & Reverse Polarity Protection
- -65 V input reverse voltage rating
- Meets ISO 7637-2 transient requirement with TVS diode
- Functional safety capable (ISO 26262 and IEC 61508)

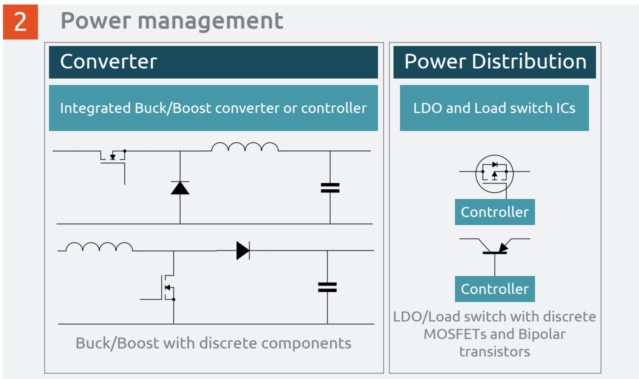
4.2 Power management

Design challenge #3:

Stabilizing and converting the incoming voltage to a level suitable for the rest of the sections of the system. The incoming voltage from the vehicle power rail can be 12 V, 24 V or 48 V. The voltage can be relatively unstable because of the long lines and wide variety of loads attached to it.

Nexperia discrete solution #1 for challenge #3

MOSFETs can be used within a local converter to achieve the needed voltage levels. The buck and boost converter topologies are useful for this task. The low power conversion levels allow for using high switching frequencies to minimize the size of passive components such as inductors and capacitors. The implemented MOSFET itself should be quite small as well [AN11119], allowing further reduction of parasitic inductances and capacitances in the PCB and device by reducing the switching circuit size and the internal connections within the package of the device. The recommended packages are the DFN2020, LFPAK33, LFPAK56D and MLPAK33.



Contrary to the MOSFETs for load switches, the MOSFETs chosen should have improved switching performance, which requires a larger R_{DSon} resistance. The large values of the drain-source resistance ensure that the die inside the MOSFET is small and therefore requires a minimal amount of energy on the gate and has low switching losses on the output. The losses occurring during switching relate mostly to the input and output capacitances and charges from the datasheet parameters. The recommended Nexperia technologies have endings H (T9 technology, for 12 V vehicle architecture) and L (T12 technology, for 48 V vehicle architecture) for example: BUK9V13-40H or BUK9Q14-80L.

Nexperias T9 40V technology MOSFET portfolio

Robust automotive silicon technology

- Beyond AEC-Q101
- Superjunction technology
- Fault condition tolerance
- Avalanche ruggedness
- Superior SOA performance

LFPAK packaging technology

- BLR performance
- High ID capability
- High power density
- Exceptional quality performance
- Zero defect programme

However, to compare available MOSFETs effectively, engineers should perform their own double pulse testing (illustrated in Fig. 9) to find a device with the best efficiency and switching behaviour ratio. More information can be found in Nexperia Application Note AN90011.

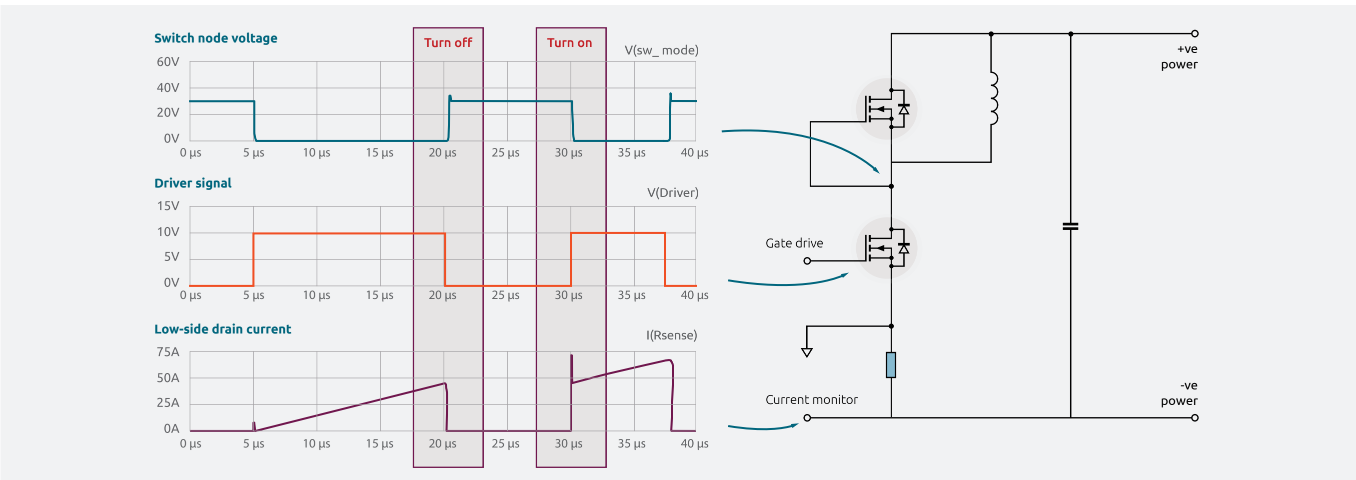


Fig. 9 Double pulse testing waveforms and circuit

Nexperia discrete solution #2 for challenge #3

The freewheeling MOSFET can be replaced by a switching diode [AN11550] as seen in Fig. 10. This move simplifies the control and design of the circuit but increases conduction losses. The employed diode should have low forward voltage drop and leakage current, as well as good heat dissipation capabilities. For more details on diodes, please see Nexperias Diodes Handbook.

Nexperias Trench technology Schottky diodes show very good switching behaviour. Compared to their planar counterparts they have lower reverse recovery charge and smaller reverse recovery current overshoot. This results in a better efficiency at high switching frequencies, which in turn results in less losses and cooling requirements of the converter. This is shown in Fig. 11 in case of a 48 V to 12 V switching converter.

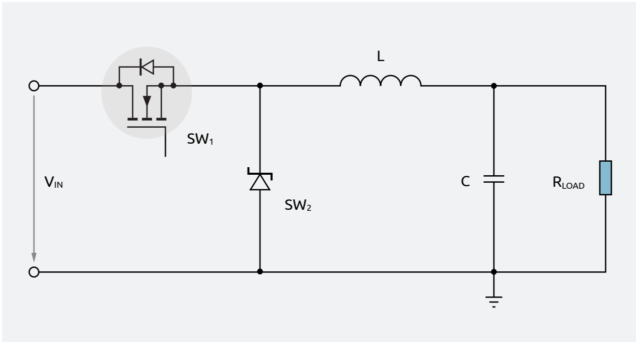


Fig. 10 Asynchronous Buck converter with MOSFET and Schottky diode

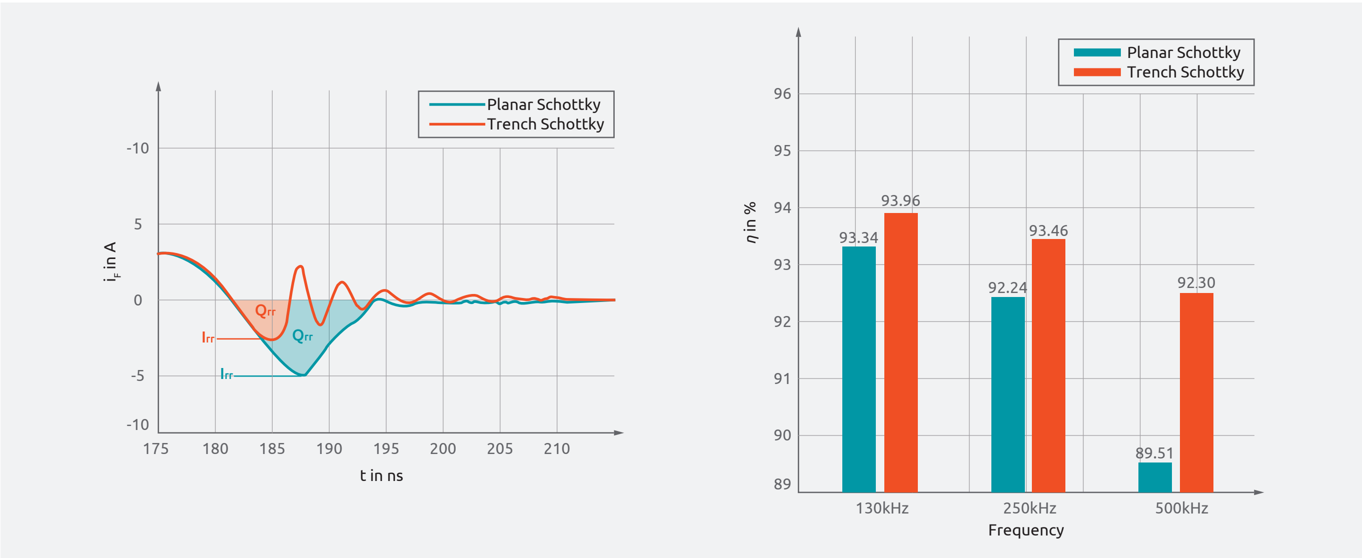
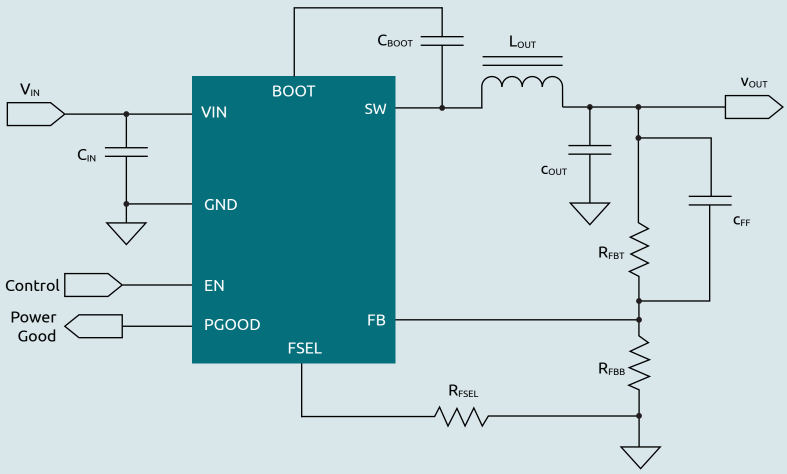


Fig. 11 Trench Schottky diode behaviour in a 48 V to 12 V switching converter: reverse recovery waveforms (left) and converter efficiency (right)

Nexperia integrated solution for challenge #3:

Voltage conversion can be achieved by a dedicated switching IC with internal devices. Such is the NEX40400 for 40 V input (12 V systems), 600 mA output and NEX40101 for 100 V input (48 V systems), 1 A output current respectively. These devices have a wide range of input voltage capability in a small package. They also have low standby current for low battery usage and they are also EMI friendly and easy to design in.

Suggested Nexperia integrated converter NEX40101-Q100



- Wide input voltage range from 6 V to 100 V
- Low quiescent/shutdown currents
- Integrated power FETs
- Near constant frequency adjustable up to 1 MHz
- Low min t_{ON} and t_{OFF} (100 ns / 140 ns)
- Peak & Valley current limit prevents current run-away
- Selectable PFM or FCCM operation
- Thermally-enhanced package (EPAD SO-8)

Design Challenge #4:

The next challenge in voltage conversion is achieving the voltage levels necessary to drive the microcontroller's core in charge of the camera ECU. The voltage levels at the output of the dc/dc converters are too high and might be variable or ripely. Therefore, they need further reduction to 1-1.8V and finer regulation. This step can generally be achieved by two different means: switching converter and regulated voltage drop.

Nexperia discrete solution #1 for challenge #4:

The solution for regulated voltage drop can also be realized using discrete components and integrated solutions alike. The devices employed here will bear simultaneously voltage across and current through their terminals, incurring substantially more losses. As the devices are required to be operated in the linear operation mode, rather than switching, bipolar transistors (BJTs) are the device of choice in this case. A solution to employing a BJT to regulate an output voltage is depicted in Fig. 12. Detailed information about BJT design in can be found in the Nexperia BJT handbook.

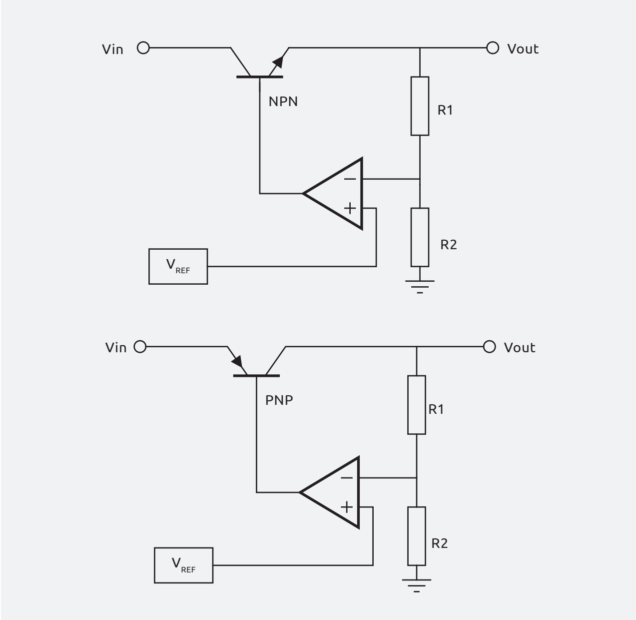


Fig. 12 LDO realisation with BJT

Nexperia has a large portfolio of low V_{CEsat} devices that are suitable for linear mode applications. The below table shows a comparison of some of them.

Key requirements	V_{CEsat} (3 A) [V] (max.)	I_c [A]	H_{fe} (2 A) (min.)	V_{BEon} [V] (max.)	V_{CE0}	Package
PBSS4310PAS-Q	0.11	3	275	0.845	10	SOT1061D
PBSS4620PA-Q	0.17	6	260	0.9	20	SOT1061
PBSS4021NX-Q	0.1	7	300	0.85	30	SOT89
PBSS4330X	0.3	3	180	1	40	SOT89

Products with "PA" in their name are available in a miniaturised 2 mm × 2 mm leadless package, while products with "X" in their name come in a SOT89 package (4.6 mm × 4.25 mm). The thermal performance of these devices for different load currents is shown in Fig. 13. Despite their small package size, the DFN2020 devices show superior thermal performance.

The required reference voltage can be obtained in a few ways. Where lower accuracy voltage regulation and larger output currents (in the double-digit mA range) are required, a Zener diode, with V_Z larger or equal to the desired output voltage and the maximum base emitter voltage can be used (Fig. 14). Whereas a more precise low dropout (LDO) regulator uses a shunt regulator like the TL431 or TLVH431 to drive the pass BJT (Fig. 15)

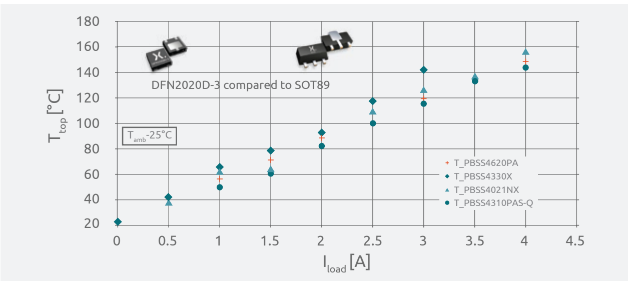


Fig. 13 Thermal performance of the BJTs for different load currents

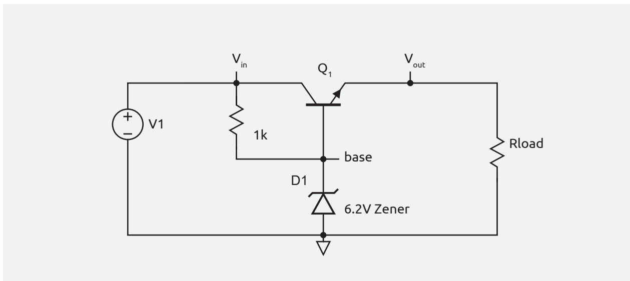


Fig. 14 Linear regulator using a Zener diode

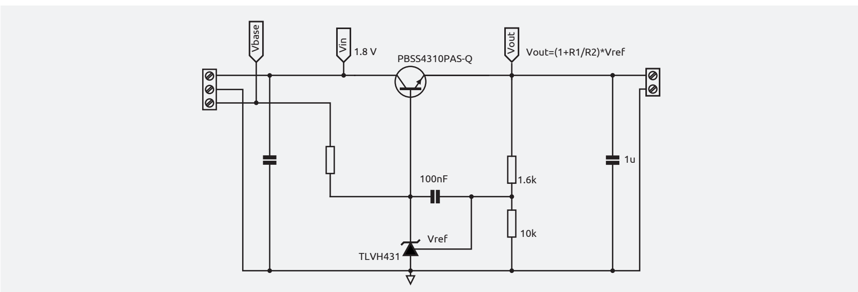


Fig. 15 A Circuit schematic showing a 1.8 - 1.45 V, 3 A voltage regulator with a low-V_{CEsat} BJT and shunt regulator

Nexperia discrete solution #2 for challenge #4

Zener diodes can also be used on voltage rails to stabilise the supply voltage. The simple way of implementation allows the design engineer to employ expensive integrated voltage regulators whilst providing satisfactory output voltage quality. In case of an overvoltage, care should be taken not to damage the Zener diode. To prevent large currents from flowing through it, a resistor can be connected in series. In this case, however, the dynamic resistance increases, and at large currents, the voltage at the load side might be too high.

The Zener diode voltage is chosen to be equal to the desired output voltage. The series resistor should be low enough not to cause too big voltage drop at the highest expected load current. Also, it should allow for a low amount of current (0.5 mA) through the Zener diode in maximum load situations to keep it within the voltage limiting part of its characteristics. If this current is not accounted for, the voltage might exceed the desired level at the output.

Nexperia's 50 µA BZX family offers a good solution with a wide range of voltage and packages (leaded and leadless) available. To ensure more precision in the output voltage value Nexperia's A-selection provides Zener diodes with 1 % tolerance beside the standard 2 % and 5 % options, to avoid design in margins.

To avoid the voltage overshoot in case the application suffers from them, perhaps due to the 0.5 mA additional current not been designed in, Nexperia's PZU family provides a footprint compatible replacement.

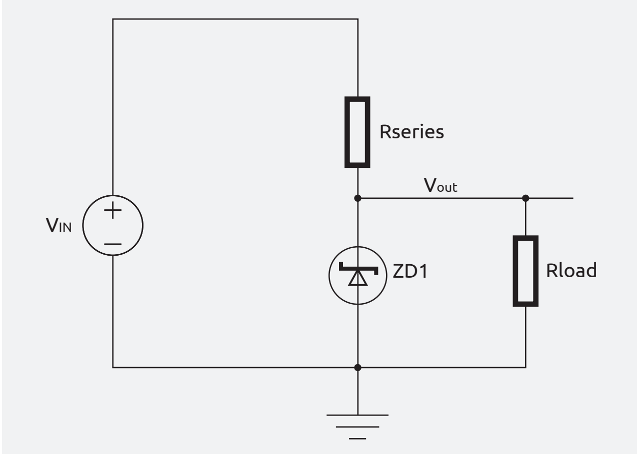


Fig. 16 Voltage stabilisation with a Zener diode

Suggested Nexperia Zener Diodes

BZX series

- Operating point specified at 50 µA
- Working voltage range: nominal 1.8 V to 75 V
- Voltage tolerance about ± 5 % (± 1 % available)

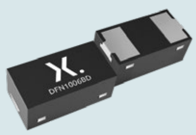
PZU series

- Low-differential resistance and low leakage Zener diodes
- Overswing proof design
- Working voltage range: nominal 2.4 V to 51 V
- Voltage tolerance B= ±5 %, B2= ±2 %

SOT23

SOD323F (SC-90)

SOD323 (SC-76)



DFN1006BD-2 (SOD882BD-2)

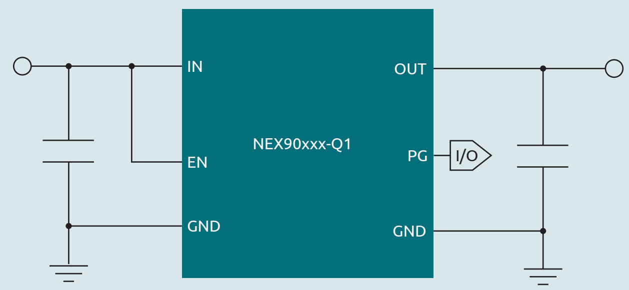
Nexperia integrated solution for challenge #4:

On the other hand, a different solution is to employ Low DropOut (LDO) regulators. Nexperia offers 150 mA (NEX90x15-Q100) and 300 mA (NEX90x30-Q100) LDOs that feature low quiescent current (typical 5 µA) and a wide input voltage range of up to 40 V with up to 45 V transient voltage. They are suitable for cold crank and start/stop automotive conditions. The LDOs benefit from Nexperia's expertise in package development and can handle excessive heat dissipation. The LDOs also feature an enable pin that can serve to turn a part of the circuit off when it is not needed (such can be a comms port that is not used), and a Power good pin, that can indicate a potential short circuit in the load.

For loads that need a stable voltage level but are off the main PCB board, tracking LDOs are recommended. The NEX91207-Q100 (70 mA) and NEX91x15/30-Q100 (150 mA and 300 mA) have a variaety of integrated protection features to protect against reverse current, short to battery and GND, reverse battery connection and short circuit. They have a wide input voltage range 4 V to 40 V to sustain cold crank and load dump transient conditions. The output is set by a reference voltage applied to the EN/ADJ pin and the output will track this voltage with high accuracy (5 mV tolerance).

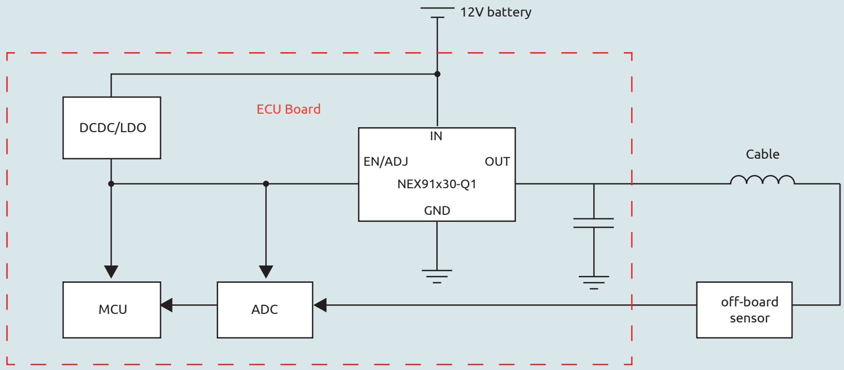
Thanks to the protection features of the device, any disturbance coming from the outside of the board will not effect the main power network on the board connected to the device IN terminal. They are also availiable in packages that enable drop in replacement for popular LDOs.

Suggested Nexperia LDOs: NEX90530-Q100/NEX90515-Q100



Suggested Nexperia tracking LDO NEX91x30/15-Q100

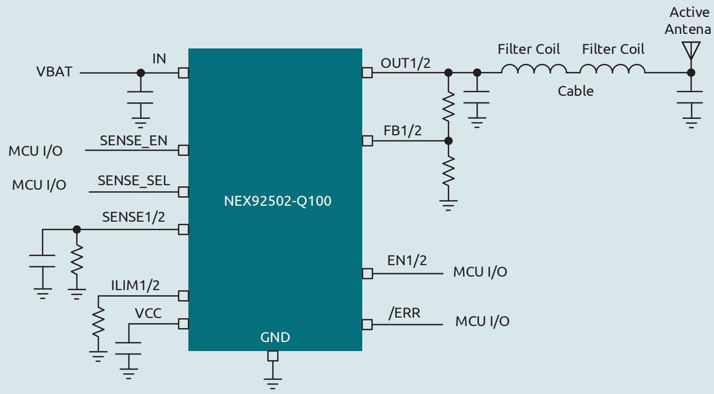
- 4 V to 40 V wide input voltage range (abs: -42 V to 45 V)
- Output voltage range: 2 to 40 V (-5 V to 45 V abs max)
- Ultra-low output tracking tolerance: ± 5 mV
- High PSRR: 80 dB@100 Hz
- Low dropout: 400 mV (typ.) @5 V/300 mA
- Low quiescent current (I_Q): 50 µA (typical)
- PG indicator for UV&OV
- Robust protection: reverse current/ reverse battery/short to battery/short to ground/t hermal shutdown
- Stable with small ceramic capacitor C_{OUT}= 4.7 µA
- Active discharging
- Package SOIC-8 EP with 3 different pin-out



While tracking LDOs are intended to follow internal voltage level and transmit it to mostly off-board loads, antenna LDOs are there to provide targeted voltage levels for the same loads. The antenna LDOs have accurate current sense even at light load, internal back-to-back MOSFETs saving system level costs and employ reverse current protection as well as full diagnostics to identify faults.

Suggested Nexperia Antenna LDO NEX92x30-Q100

- Input voltage range: 4 V to 40 V
- Output voltage range: 1 V to 20 V
- I2C interface supported w/ 8-bit ADC (C version)
- Dual channel o/p: 300 mA o/p current capability per channel
- High accuracy current sense: ±8 % @ I_O =5 mA
- Low dropout voltage (max. 500 mV @ 100 mA)
- Full diagnostic & protection
  - Short to battery/ground
  - Reverse battery/polarity/current
  - Open load detection
  - Thermal shutdown
- Operating junction temperature range: -40 °C to 150 °C (grade 1)
- Thermally enhanced HTSSOP-16 package/QFN-16 (I2C)



300 mA Dual/single channel Antenna LDO with current sense

For the summary on the roles of the different LDOs please see Fig. 17;

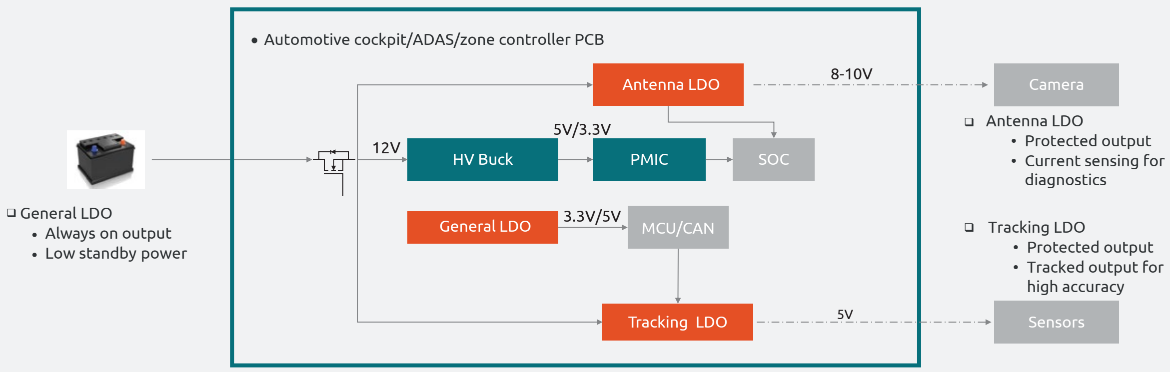


Fig. 17 Roles of different LDO types in a controller PCB

Design challenge #5:

Realizing voltage monitoring, system wake up or other functions in the power management section without the use of the main processor. The main processor might be in sleep mode or disabled by the absence of supply voltage.

Nexperia solution for challenge #5:

Voltage monitoring can be achieved using discrete components. In the case illustrated in Fig. 18, once the monitored voltage drops, both transistors stop conducting, and the microcontroller or SoC receives a low voltage on its input pin. The schematic can be realized for different voltage levels utilizing general-purpose switching diodes, transistors and RETs [AN90024].

System wakeup can also be realized via a communication transceiver like IVN or CAN by enabling the main DCDC converter or auxiliary LDOs via its inhibit pin. On Fig. 19, a simple OR circuit using small signal switching and Schottky diodes is proposed.

Discrete MOSFETs and BJTs are now offered in DFN packages [AN90023] offering significant board space saving and better thermal performance compared to conventional leaded SMD devices. There unique feature of side wettable flanks allows for Automatic Optical Inspection, saving cost in production by eliminating the need for x-ray solder inspection. Automotive qualified MOSFETs are now offered in tiny DFN1110D-3 packages for 60 V N-channel and 50 V P-channel devices.

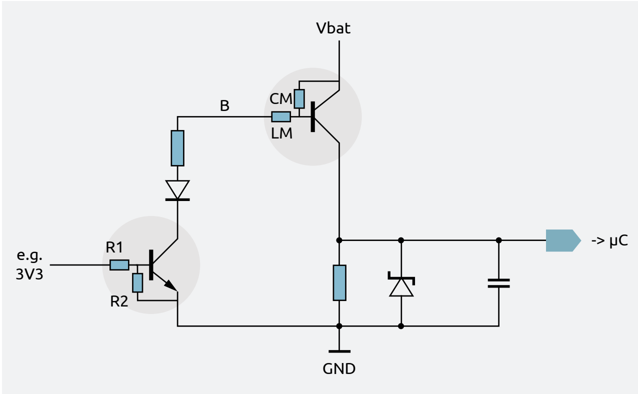


Fig. 18 Voltage monitoring circuit using RETs and Zener diodes

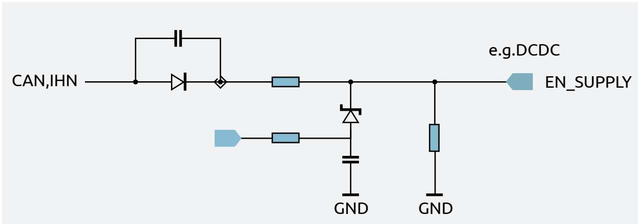
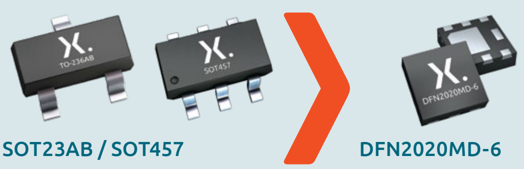


Fig. 19 Wake up circuit using small signal switching and Schottky diodes

Suggested advanced Nexperia DFN packages



SOT23AB / SOT457
Occupied PCB area 11.4 mm²

DFN2020MD-6
Occupied PCB area 5.1 mm²
Space saving 55%

SOT323
Occupied PCB area 6.2 mm²

DFN1110D-3
Occupied PCB area 2.5 mm²
Space saving 60%

SOT23
Occupied PCB area 9.9 mm²

DFN1110D-3
Occupied PCB area 2.5 mm²
Space saving 75%

SOT363
Occupied PCB area 6.2 mm²

DFN1412-6
Occupied PCB area 2.7 mm²
Space saving 55%

Design challenge #6:

Controlling the power supply to parts of the design that don't need power all the time.

Nexperia discrete solution to challenge #6

Parts of the design, like communication interfaces or de-foggers, might not need to be powered on all the time to reduce power consumption. Parts of the design, like demanding video processors, might need to have a certain power up and down sequencing routine to prevent damaging them. In case inrush current happens, due to large capacitance, it needs to be limited.

A load switch [AN50020] serves to limit the power consumption of loads that are not needed to be on. An additional role can be the protection of the loads from the damaging effects of short circuits and overvoltages by disconnecting the protected circuit. This is usually tested by applying ISO standard conducted transients to achieve compliance [AN50007].

A discrete realisation can be established with power MOSFETs. In the case of P-channel MOSFET, a single signal MOSFET is needed to control the power MOSFET. N-channel MOSFETs have superior performance to their P-channel counterparts. However, employing an N-channel MOSFET in the same position requires additional circuitry (charge pump) to pull the gate voltage above the supply line voltage in order to control the MOSFET.

Nexperia's portfolio of P-channel devices covers applications on all automotive distribution voltage levels from 12 to 48 V as well as in a range of power levels as seen in the table below.

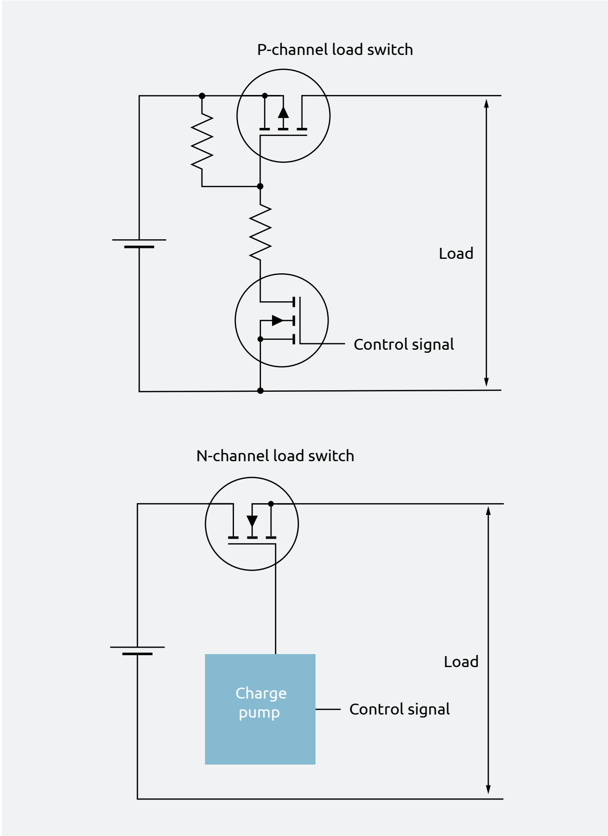


Fig. 20 Load switch realisation with P-channel and N-channel MOSFETs

Nexperia's P-channel MOSFET portfolio

V_{DS}	 LFPAK56	 LFPAK33	 MLPAK33	 DFN2020MD-6
20 V				19-122 mΩ
28 V/30 V	10-19 mΩ		7.5 & 21 mΩ	24, 40, 50 mΩ
40 V	14-24 mΩ		12 & 26 mΩ	43 mΩ
60 V	33-61 mΩ	61 mΩ	66 mΩ	120 mΩ
80 V	55 mΩ			120 & 220 mΩ

On the other hand, this function can be addressed with BJTs. While BJTs are thought of as higher power loss components than MOSFETs, in some cases they might enjoy a few advantages. Nexperia's low V_{CEsat} BJT portfolio can have Collector-Emitter voltage as low as 30 mV and a current amplification of 200 to 600. This enables them to be competitive with MOSFETs on the conduction losses and have less demanding gating requirements.

Fig. 21 shows a load switch realized with two BJTs, a high-side switch (T1) and a control transistor (T2). Reverse currents from the output to the input are blocked, to a limited extent, by the inherent feature of BJTs, which might be important in case the input voltage collapses and there is charge in capacitors on the load side. The low turn on voltage at the base of roughly 0.7 V for the BJTs enables them to switch at low voltages, such as the ones required for processing. A further advantage of using a low V_{CEsat} BJT in this application is its good ESD robustness.

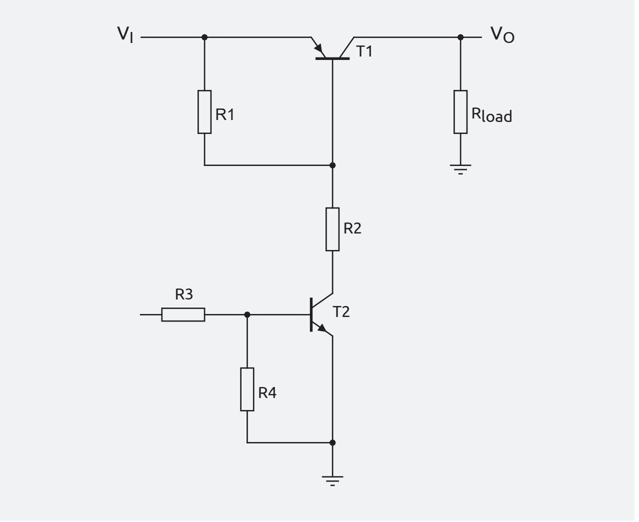
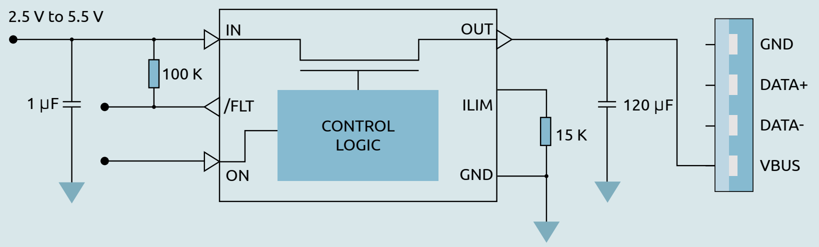


Fig. 21 Load switch realisation with low V_{CEsat} BJTs

Nexperia integrated solution for challenge #6:

Integrated load switches, like the NPS4053-Q100, can be used to activate parts of the camera design instead the discrete alternatives [AN90052]. Integrated load switches inherently require less design-in effort, smaller board space and fewer external components as well as integrated protection functions, albeit they are typically produced for lower current ratings than their discrete solution counterparts. They might be ideally suited for camera applications, due to the low power requirements and space constraints.

NPS4053-Q100 integrated load switch



- Input voltage range: 2.5 V to 5.5 V
- Maximum continuous current: 2 A
- ON resistance: 55 mΩ
- Adjustable current limit: 110 mA to 2.5 A
- ±6 % current limit accuracy
- Constant current during current limit
- No body diode when disabled (no current path from pin OUT to pin IN) Active reverse voltage protection
- Built in soft start
- UL 62368 recognition
- SOT457 (TSOP6) and SOT8044-1 (HWSON6) package option
- 15 kV ESD protection as per IEC 61000-4-2

Power management

The application of a load switch can limit inrush current to controllers, preventing damage to the microcontroller itself, pulling down the output voltage of the DC/DC converter or damaging the DC/DC converter itself. A typical placement of the Load switch can be seen in Fig. 22 with the illustration of the change in the supply current.

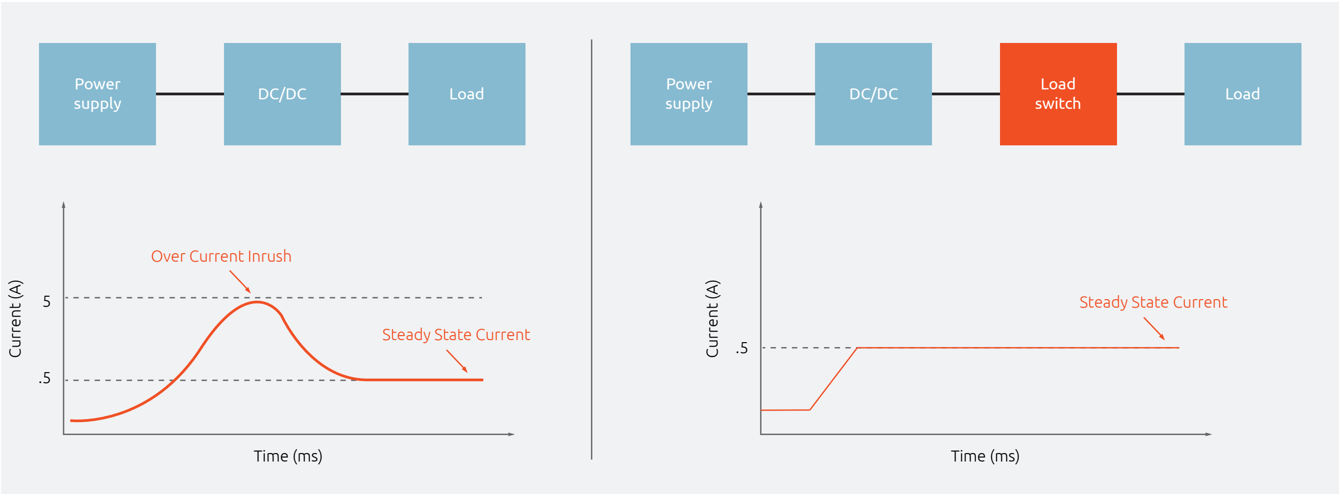


Fig. 22 Load switch placement block diagram and current limiting functionality

Load switches and smart high side switches also enable power sequencing to the complete board or individual controller. The sequencing can be controlled from an auxiliary, start-up controller and executed by integrated or discrete switches:

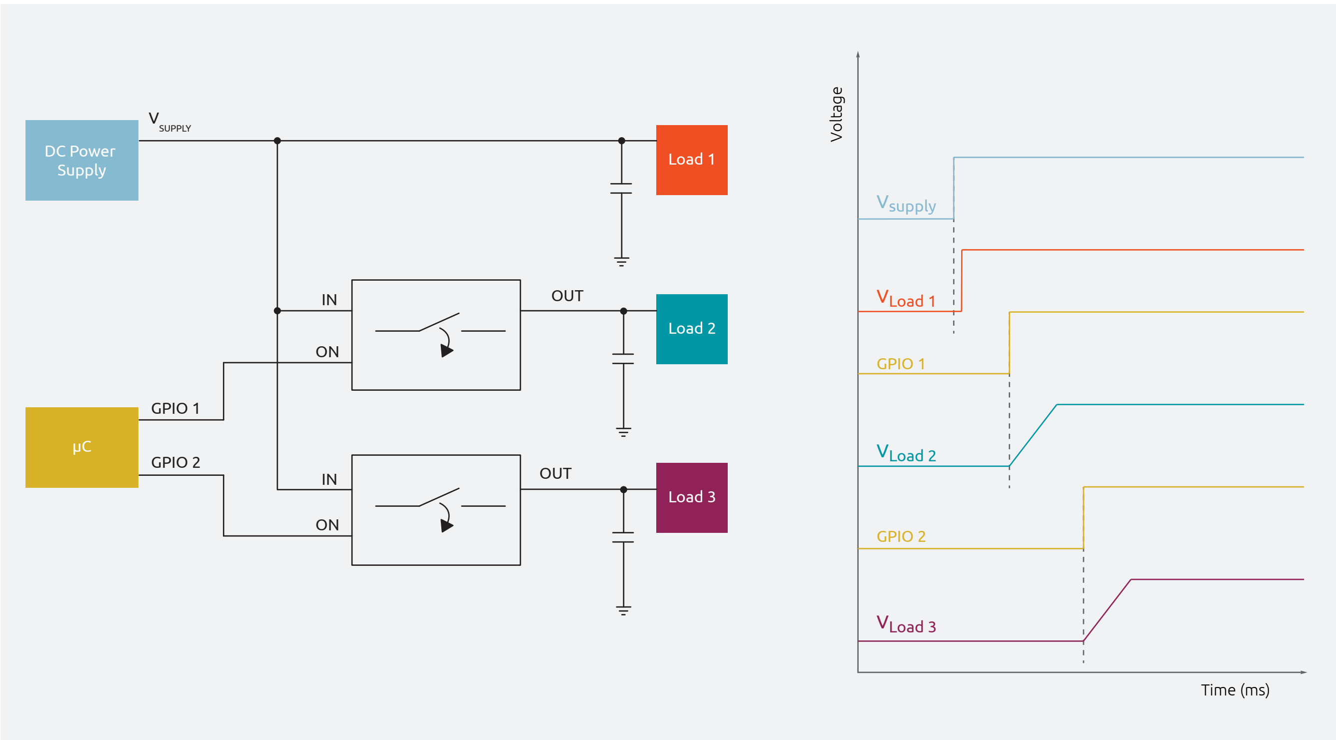


Fig. 23 Power sequencing with discrete or integrate load switches

4.3 Communication interface

Design challenge #7a:

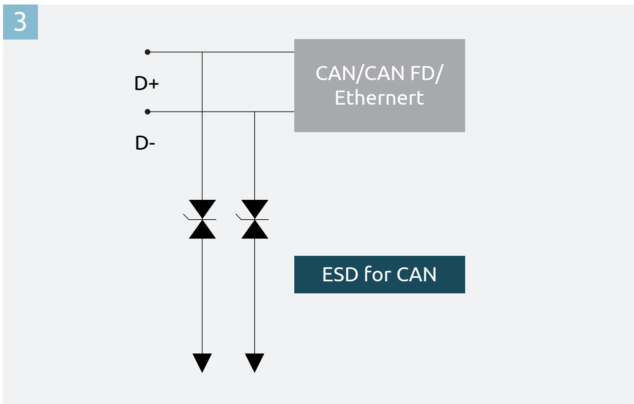
Protecting data lines from external voltage surges and bursts.

CAN and Ethernet are typical in-vehicle networks used for interfacing the automotive cameras, as fast information flow is required.

ESD devices are tested in combination with the CAN transceiver. Their role is to ensure the network's ESD robustness and protect the transceivers. In a combination test with the transceiver, the device must demonstrate RF immunity and low RF emissions, as well as immunity against transients and ESD. To pass the test of immunity for RF disturbances, a higher voltage is needed to activate the device. However, a low clamping voltage is crucial for ESD protection performance. Thirdly, as CAN lines can be connected to the car battery, transient events, causing disturbances like 28 V for 1 second also need to be survived. Therefore, exact stand-off voltage (V_{RWM}) and low dynamic resistance are key to a good ESD protection device.

Other requirements like the maximal device capacitance and matching of the capacitances of both lines are set by the system owner or external circumstances like the required communication speed and length of communication lines, number of communication nodes etc. For more details, check out AN11882.

A generic solution for realizing the protection for CAN is shown in Fig. 24. Any of the IVN, CAN or CANFD type devices can be used in the figure. IVN devices have higher capacitances (>10 pF) that can perfectly cover CAN communication (up to 500 kbps) but might be too high for CANFD (5 Mbps).



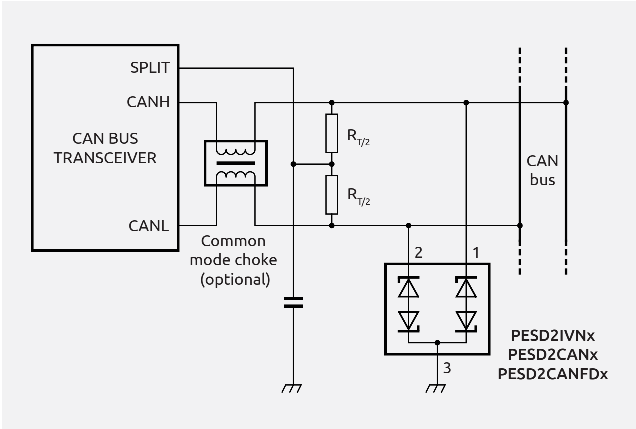


Fig. 24 Generic CAN interface with ESD protection device

Communication interface

Nexperia Solution for Challenge #7a:

ESD devices serve predominantly to protect data lines [ESD Automotive Application Guide]. Because of their low capacitances, they enable high data rates to be communicated. Except for the power absorbing capacity of the device, care should be taken for adequate breakdown voltage and dynamic resistance of the device (see Fig. 25 for more selection criteria). If the latter two are high, in case of a large surge event, the current flowing through the device can make the clamping voltage too high for the protected circuit. For a thorough overview of protection concepts with ESD devices, refer to Nexperia's Automotive ESD handbook.

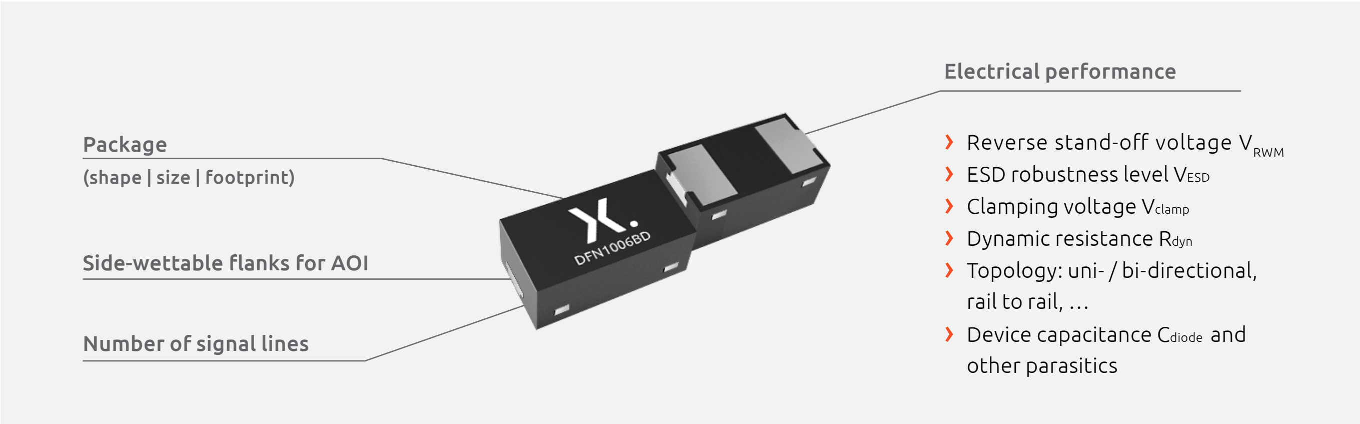


Fig. 25 ESD devices selection criteria

Alternatively, Ethernet can be connected directly to the camera module interface, in which case the below protection diagram can be used. The OPEN Alliance proposes two possible external ESD protection devices. As shown in Fig. 26, one can be placed at the connector (ESD_1, focus on high surge immunity) and one at the PHY interface (ESD_2, focus on low capacitance). The specification allows to use of none, one, or both devices to achieve the desired ESD robustness in Ethernet applications [AN90039]. The external ESD protection at the PHY interface is considered a part of the PHY from the view of the specification.

The PHY interface, in combination with the external protection, needs to pass all requirements that apply to the PHY interface alone. The protection at the connector must comply with the OPEN Alliance specification for external ESD protection devices. Nexperia ESD devices were first to be approved by OPEN Alliance. From a system perspective, the external ESD protection at the connector is superior and the best way to design a robust interface. Please find suggested devices for both positions in the device list section.

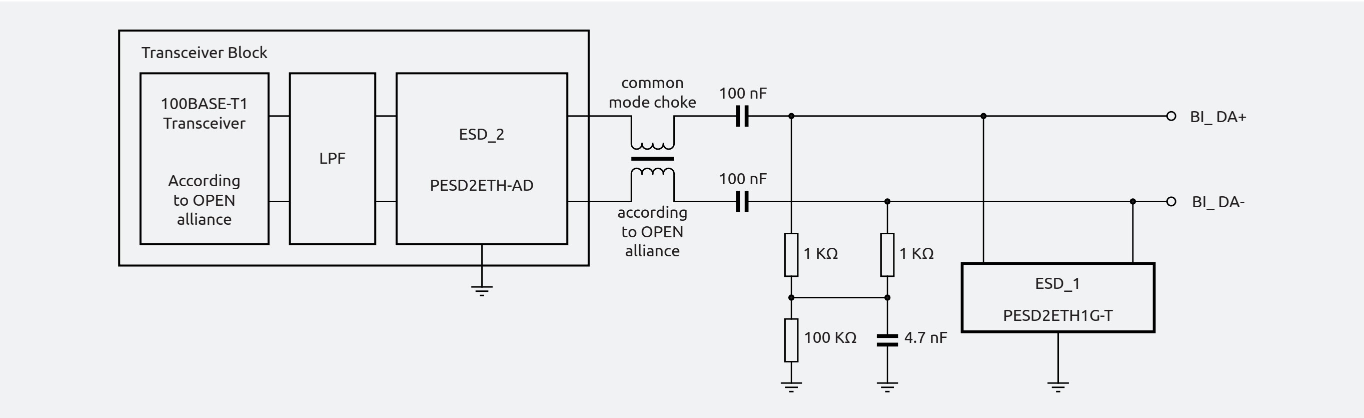


Fig. 26 Interface topology for 100BASE-T1 according to OPEN Alliance with placement of ESD protection at the connector and as part of the transceiver block

Design challenge #7b:

Automotive architectures show a trend towards increasing battery voltage. These voltages necessitate higher level of protection for the communication lines.

Nexperia Solution for Challenge #7b:

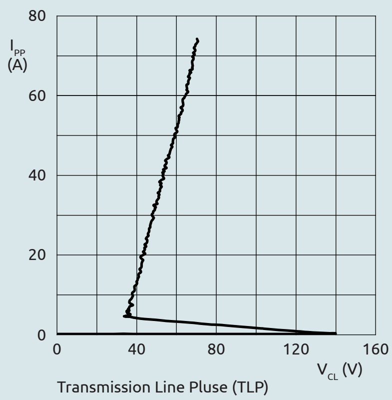
Since communication networks could accidentally be shorted to voltage sources like the car battery, ESD protection devices at the CANL and CANH lines must be able to withstand higher voltage levels. To safely withstand jump-start conditions or where two 12 V batteries are connected in series in the case of a commercial vehicle, Nexperia's ESD protection devices meet the minimum required standoff voltage (V_{RWM}) of 24 V and adhere to the ISO7637-2 and ISO 16750-2 ESD protection standards. According to these protection standards, ESD protection devices with operating voltages typically above 32 V are required to safeguard sensitive signal lines in 24 V board nets. Nexperia has designed devices in its new portfolio to have a maximum reverse standoff voltage of 36 V and to provide up to 22 kV of ESD protection. This performance is combined with a low clamping voltage of V_{CL}= 48 V to provide intra-vehicle networks with excellent system-level robustness. Nexperia also offers an ESD protection device for 48 V networks which meets the additional requirements defined in ISO 21780. For maximum flexibility, all devices (12/24/48 V) in this portfolio are available in SOT23 and SOT323 packages with three different capacitance classes of 4 pF, 6 pF and 10 pF, which help ensure smooth communication between interfaces without impacting signal integrity.

Device	Package	V_{RWM} [V]	C_d [pF]	V_{ESD} [kV]	Board-Net [V]
PESD2IVN2x-T	SOT23	24/27	<17	30	12
PESD2IVN2x-U	SOT323				
PESD2CANFD2x-T	SOT23	24/27	3/6/10	30	12
PESD2CANFD2x-U	SOT323				
PESD2CANFD2x-QB	DFN1110D-3	24/27	3/6/10	30	12
PESD2CANFD2x-QC	DFN1412D-3				
PESD2CANFD36x-Q	SOT23	36	10/6/4.3	<23	24
	SOT323				
PESD2CANFD3x-QB	DFN1110D-3	33/36	10/6/4.3	<23	24
PESD2CANFD36x-QC	DFN1412D-3	36			
PESD1CANFDxL-Q	DFN1006-2	24/30/33/36	<11	>20	12/24
PESD1CANFDxLS-Q	DFN1006BD-2				
PESD2IVN48T-Q	SOT23	48	8	30	48
PESD2CANFDx	SOT23	54/60/72	3/5	30	48

For 10Base-T1s Ethernet protocol, Nexperias ESD protection devices were the first to be approved by the OPEN alliance. They have a trigger voltage of over 100 V, low capacitance for smooth data transmission and high ESD robustness.

10Base-T1s ESD protection devices

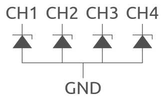
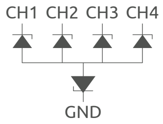
Device	Package	V_{RWM} [V]	$C_{D\ typ}$ [pF]	V_{ESD} [kV]
PESD2ETH10T-Q	SOT23	75	0.38	15
PESD1ETH10L-Q	DFN1006-2	75	0.35	15
PESD1ETH10LS-Q	DFN1006BD-2	75	0.35	15
PESD2ETH10BLG-Q	DFN1006LD-3	75	0.35	15



Transmission Line Pluse (TLP)
t_p = 100 ns t_r = 1 ns

Communication interface

The PESD4USBx series of devices are recommended for SerDes communication. They have only 0.2 pF maximum capacitance per channel. For good protection, they have extremely deep snapback combined with a low resistance of 0.4 Ω. To ease routing they have ‘pass-through’ signal routing, matching capacitance with <0.05 pF signal lines and matched 0.5mm trace spacing.

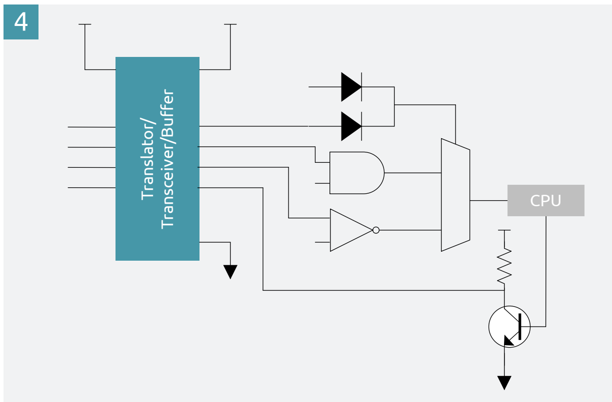
Part	Configuration	Graphic Symbol	V_{RWM} (V)	C_{Dmax} (pF)	ESD_{max} (kV)
PESD4USB3Ux	4 lines Unidirectional		3.3 V	0.34	15 kV
PESD4USB5Ux			5 V		
PESD4USB3Bx	4 lines Bidirectional		3.3 V	0.25	
PESD4USB5Bx			5 V		

4.4 Signal processing

Design challenge #8:

Interfacing blocks and devices that operate at different voltage levels and have different input and output configurations.

Nexperia Integrated Solution for Challenge #8:
Processor technologies (microcontrollers, SoCs, ASICs, microprocessors) are moving to smaller process geometries and therefore the core and I/O voltages are scaling down. As a result there are more I/O level mismatches likely to arise between processors and peripheral devices. Voltage translators are required between process families that are usually connected to 5V or higher supply (HC(T), AHC(T), VHC(T) and LVC), 3.3V (LV, LVC, LVT, ALVC) and lower supply (AUP, AVC). See Fig. 27 below for examples.



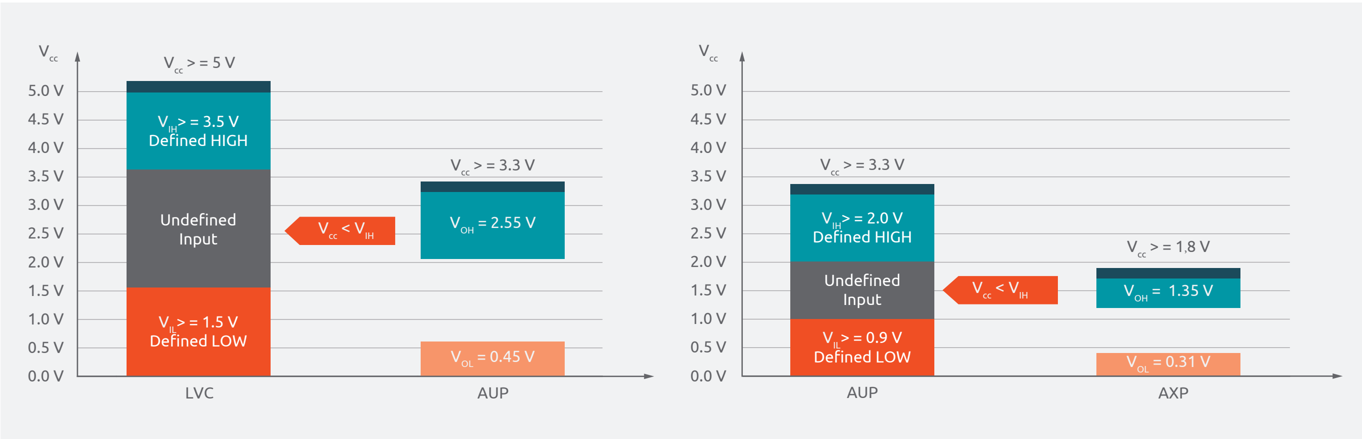


Fig. 27. Example of device families with incompatible voltage levels: LVC and AUP (left) and AUP and AUX (right).

Well-tested and proven functional blocks are sometimes used in new designs. These might be on a different voltage or technology than the rest of the design they need to be connected to. Additionally, different function blocks or different logic technologies can be at different logic levels and need interfacing.

Buffers, transceivers and translators are used in cameras to incorporate the functional blocks on different voltage levels into a single well-functioning entity. Buffers are, in essence, two inverters connected in series, while transceivers are bidirectional buffers. They can make signal integrity better between the main controller and the camera module. The two can sometimes operate on different supply voltages, which is where translators are handy.

Nexperia offers a wide portfolio of signal chain devices. They are available in a variety of packages and technologies to accommodate pin compatibility and compatibility with connecting block technologies. For complete information on Nexperia Logic devices, refer to the Logic handbook.

Level translation devices provide optimal solutions of overcoming I/O level mismatch without sacrificing performance. They are available to address most common logic levels and interface standards such as I2C, SPI, UART, JTAG.

Increasing Bit Count

Interface	Recommended Products		
	3.6 V Maximum	5.5 V Maximum	
1-Bit GPIO, Clock Signal FET Replacement	74AVC1T45, 74AUP1T34	74LVC1T45, 74LV1T34	1-bit
2-Bit GPIO	74AVC2T245	74LVC2T45	2-bit
2-Pin JTAG/UART	74AVC2T45	74LVC2T45	
I²C	NCA9306, TXS0102, NCA970x	NCA9306, NXS0102	
MDIO / SMBus / PMBus	NXS0102, LSF0102	NXS0102, LSF0102	
SIM- Card	NXT4557	NA	3-bit
4-Bit GPIO	74AVC4T245, 74AVC4T774, 74AVC4T3144, NXU0104	NXS0104, NXB0104, LSF0204, LVC4T3144	4-bit
UART	74AVC4T245, NXU0204	NXB0104, NXU0204	
SPI	74AVC4T774, NXB0104, NXU0304	NXB0104, 74LVC4T3144, NXU0304	
JTAG / I²S / PCM	74AVC4T774, NXB0104	NXB0104	
HDMI	NXS0104	NXS0104	
SDIO/SD3.0/MMC	NXS0506	NA	6-bit
Quad-SPI	NXB0106	NXB0106	
8-Bit GPIO	74AVC8T245	74LVC8T245, 74LVC4245A	8-bit

There are several possibilities for the input and output solutions that need to be taken into account. The inputs can be:

- Clamp diode protected inputs, enables high to low voltage translations, with an additional current limiting resistor (Fig. 28)
- ESD protected to enable high to low voltage translations (Fig. 29)
- Low threshold inputs, can be used for low to high level translation
- Schmitt trigger inputs, to remove noise from signals (Fig. 30) and improving signal integrity related to slow rising signals in noisy automotive environments. Nexperia has a wide voltage range of devices available from below 1 V to 5.5 V.

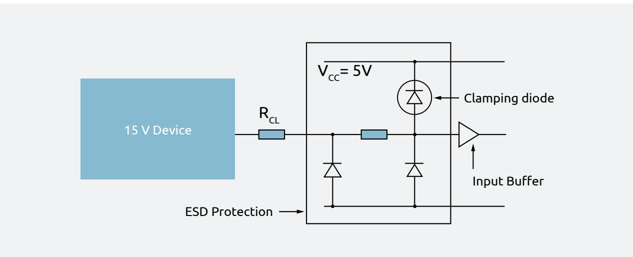


Fig. 28 Clamp diode protected input simplified schematic

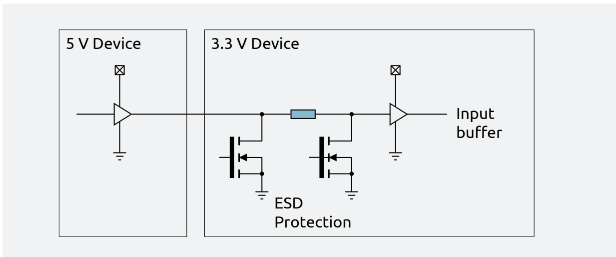


Fig. 29 ESD protected inputs simplified schematics

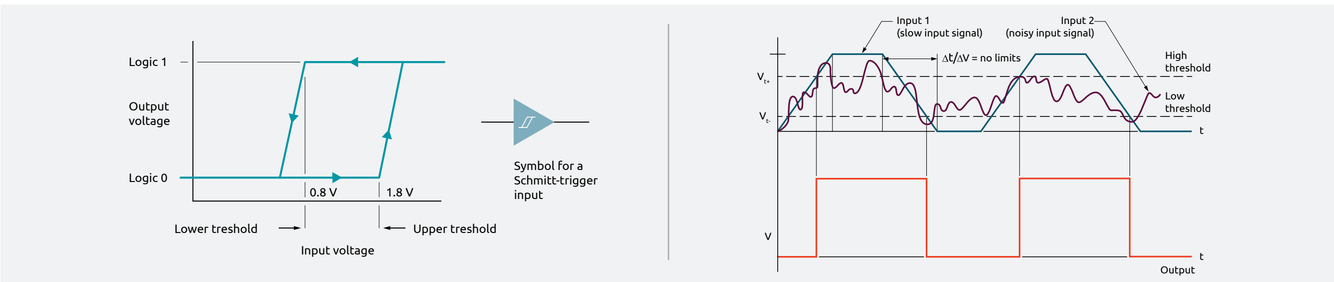


Fig. 30 Schmitt trigger inputs input hysteresis curve (left) and signal response (right)

While device outputs can be:

- Open drain outputs, enables low to high and high to low level translations (Fig. 31)
- I_{off} restricted outputs, enables lower consumption in application power-down mode
- Impedance matched to the load to prevent signal ringing in circuits with longer wiring
- Bus hold outputs: prevents floating inputs to CMOS circuits from stalling at $V_{CC}/2$ and causing shoot-through current. A weak feedback mechanism to the input pin ensures the last applied state is held at the input (Fig. 32).

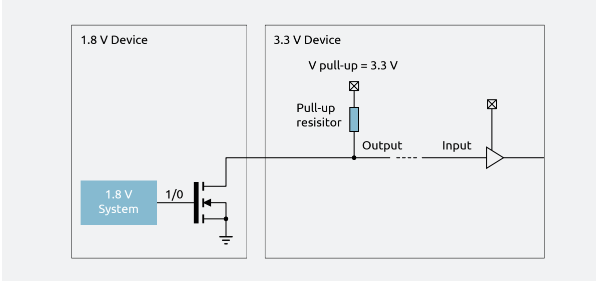


Fig. 31 Open drain outputs simplified schematic and example of utilisation.

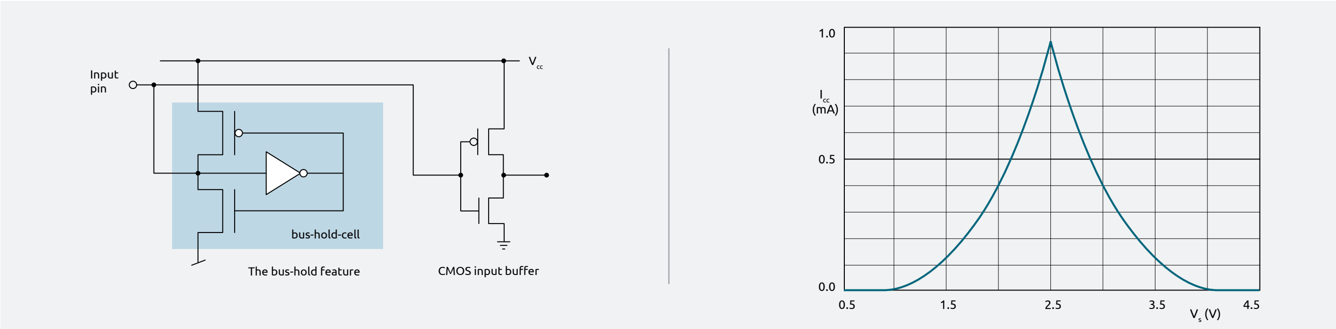


Fig. 32 Bus hold feedback functional schematic (left) and output current and voltage graph (right).

A feature of many buffers and translators is to prevent current through the device body diode when the system is partially powered down. In this way the particular device pin is protected from potentially large currents and the powered down system cannot malfunction because of partially elevated V_{CC1}. This feature is better known as I_{off} protection. See illustration in Fig. 33. Partial power down is key for power management, especially important in EV/HEVs.

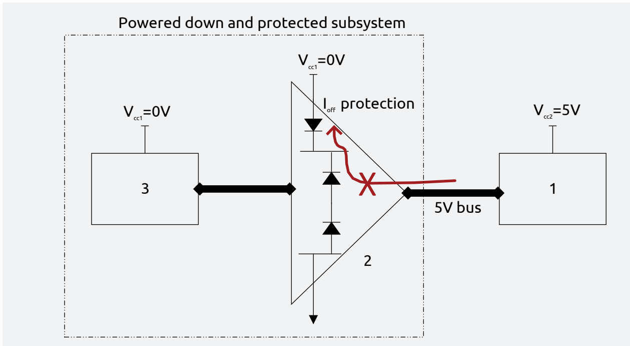


Fig. 33 Device with I_{off} protection

Interface logic is also used to increase low-drive microcontroller outputs to drive high-load peripherals. New processor I/O have limited drive strength because of low core voltage operating modes. Buffers and level translators with good drive strength supplement drive strength of processors I/O to overcome trace or cable capacitance to maintain signal quality.

Except for the voltage level of the circuits they connect, when choosing a translator, there are a number of other factors to be considered, such as speed, current drive strength, topology, and package requirements. The maximum allowed voltage level still allows the translator to operate at lower voltage levels. The newer and faster families have a lower max voltage and less current drive strength.

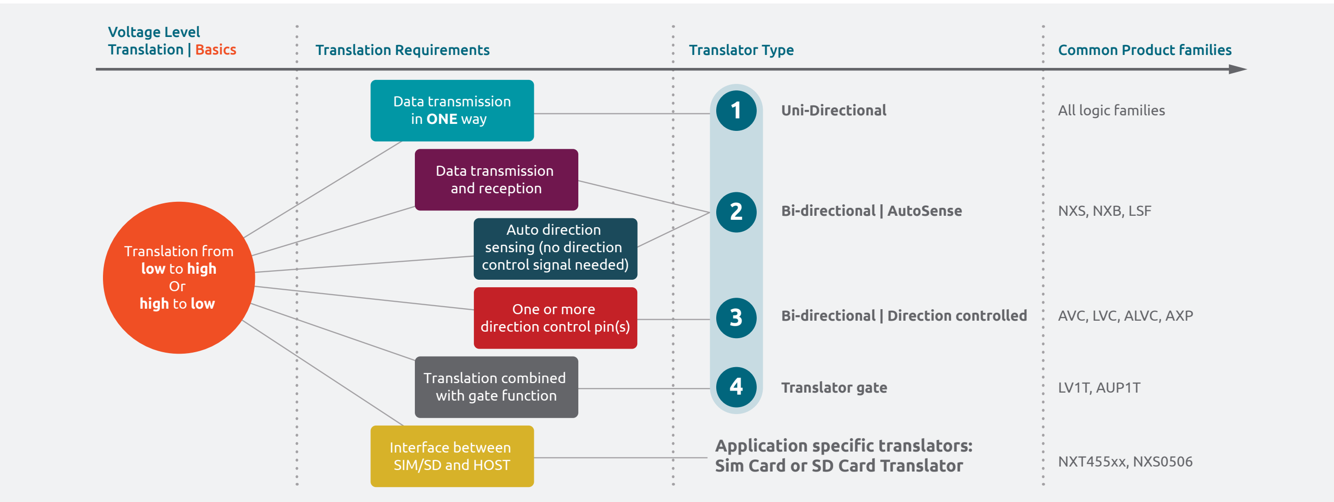
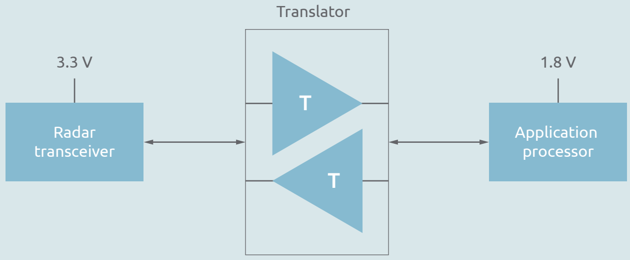


Fig. 34 Voltage translator selector tool

Interesting products to consider here are the bidirectional multi-voltage level translator LSF010x auto-sense devices [AN90033].

Suggested Nexperia Translator: LSF0101GW-Q100



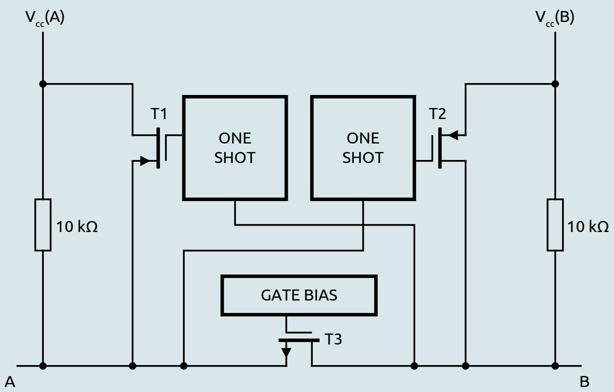
1-Bit bi-directional translator with auto-direction sensing

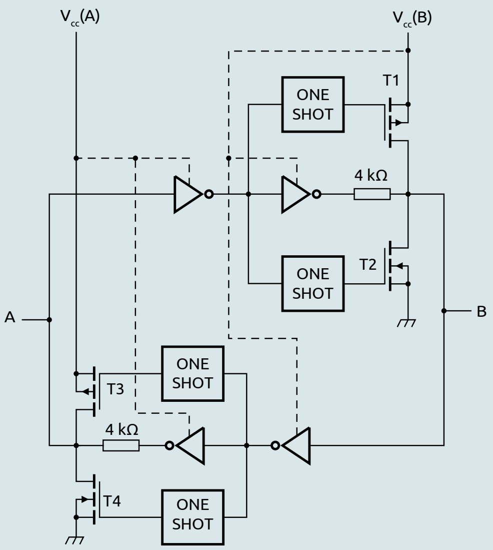
- Supply voltage from 0.95 V-5.0 V
- Data rate of 50 Mbps
- Propagation delay of 0.7 ns
- Temperature range from -40 °C to 125 °C
- Hot Insertion
- Low standby current
- 5 V tolerant I/O pins to support TTL
- Low R_{ON} for less signal distortion

The NXS0101GW-Q100 and NXB0101GW-Q100 additionally provide acceleration of the signal rising edge and rising and falling edge, respectively. By driving the output stronger, these devices achieve faster data rates. Other additional features include:

- Wide supply voltage range
- V_{cc} isolation
- Multiple package options

Suggested Nexperia Translators NXS0101GW-Q100 and NXB0101GW-Q100





Use cases that need higher data rates and higher current drive can be addressed by the advanced high-speed CMOS (AVC) and Low Voltage CMOS (LVC) series direction controlled translators, while the NXU family is intended for fixed direction use cases.

Suggested Nexperia Translator families LVC, AVC and NXU; comparison		
LVC logic portfolio enables the migration of electronic solutions from 5.5 V to lower power mixed 5.5 V / 3.3 V	The AVC family offers a solution for highest performance in 1.8 V, 2.5 V, and 3.3 V systems	NXU Fixed Direction dual supply translating buffer
› Bit counts from 1-bit to 8-bit	› Bit counts from 1-bit to 20-bit	› Bit counts from 1-bit to 4-bit › Multiple ch. directionality options
› V_{CC} spec. at 5.5V, 3.3 V, 2.5 V and 1.8 V › 5 V I/O tolerance	› V_{CC} specified at 3.3V, 2.5V, and 1.8V › Optimized for 3.3 V I/O tolerance	› Wide dual supply range (V_{CCA}, V_{CCB}) of 0.9 V – 5.5 V
› Up to 24 mA of current drive	› Up to 12 mA of current drive	› 12 mA / 5 V outputs drive
› Data rates >200 Mbps › T_{pd} is in 2 to 4 ns range	› Sub-2.0 ns max T_{pd} at 2.5 V	› Maximum Data Rate of 250 Mbps for up-translation ≥ 1.8 V to 5 V
› ESD protection › AEC-Q100 compliant options › Fully specified (-40 to +125°C) › Pb-free, RoHS compliant and Dark Green	› ESD protection › AEC-Q100 compliant options › Specified -40 °C to +125 °C › Pb-free, RoHS compliant and Dark Green	› ESD protection › AEC-Q100 compliant options › Specified -40 °C to +125 °C › Pb-free, RoHS compliant and Dark Green
› I_{off} spec for partial power down	› I_{off} for partial power down › Bus-hold options	› I_{OFF} circuitry for partial power down › Schmitt-trigger inputs › Low Power consumption › Input pins may be disconnected or floating (integrated pull-down resistor)

Nexperia Discrete Solution for Challenge #8:

Level shifting can also be realised with discrete MOSFETs. Application note AN10441 details a bidirectional solution depicted on Fig. 35. In spite of its simplicity, such a solution not only fulfils the requirement of bidirectional level shifting without a direction control signal, it also:

- Isolates a powered-down bus section from the rest of the bus system
- Protects the 'lower voltage' side against high voltage spikes from the 'higher voltage' side

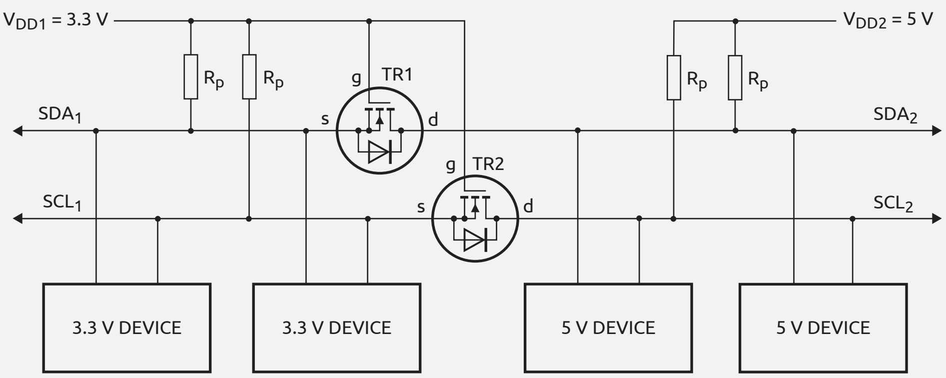


Fig. 35 Bidirectional level shifter circuit connecting two different voltage sections in an I2C-bus system

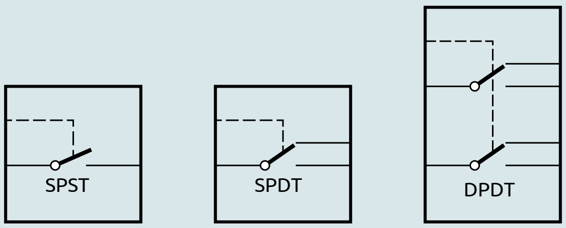
Design challenge #9:

Increasing the number of pins of the controller without upgrading the controller. The increasing number of functions the main controller needs to manage might require more pins than what the controller has.

Nexperia Solution for Challenge #9:

Analog switches can be used in cameras to expand the MCU pin count and direct multiple digital or analog input signals to ADC or digital input pins. Various configurations are possible as seen in the figure below. An example product family would be the NMUX130xxx-Q100 1.8 V general purpose SP8T-Z and 2xSP4T-Z analog switches with injection current control:

Suggested Nexperia analog switches: NMUX130-Q100



- Injection current control: Typical coupling of 30 µV/mA
- 1.8 V control logic thresholds across supply operating range
- Complete Powered off protection (V_{CC} = 0 V)
- Isolates biased digital/analog pins from back-powering V_{CC}
- Maintains Hi-Z state of analog switch
- 1.5 V to 5.5 V operating range
- Rail-to-rail operation of analog signal pins
- Pin compatible with legacy 405x/485x analog switches
- ESD protection: ±2 kV HBM and ±750 V CDM
- Specified from -40 °C to 85 °C and -40 °C to 125 °C

Design challenge #10:

Realize safety, functionality and security features independently from the main controller.

Nexperia Solution for Challenge #10:

Logic circuits, registers, analog switches and voltage translators can be used for added functionality or additional layers of security outside of the main control processor. This can be alarm logic ('OR'-ing alarm signals), realising safety logic outside of the processor for additional safety or increasing the number of GPIOs and A/D converters by using multiplexers and analog switches. Because of the large number of process families available, the below table is provided to ease selection:

Nexperia Logic circuits, Registers, Analog Switches and Voltage Translators Overview

High voltage families

		HEF4000B	HC(T)	AHC(T)	VHC(T)	LV-A(T)	CBT(D)	LVC	LV1T	NXS(B)	LSF
Parameters	Supply voltage (V)	3.0 - 15.0	2.0 - 6.0	2.0 - 5.5	2.0 - 5.5	2.0 - 5.5	4.5 - 5.5	1.65 - 5.5	1.6 - 5.5	1.65 - 3.6 2.3 - 5.5	0.95 - 5.0
	Propagation Delay (TYP) (ns)	90	9	5	4	3.4	0.25	1.7	13.5	5.2	0.7
	Output drive (mA)	±3	±8	±8	±8	±12	N/A	± 24	± 8	-1 / ±0.02	64
	Standby Current (µA)	600	80	40	40	20	3	10	10	30 .. 70	N/A
	AEC-Q100 Grade	Levels 1, 3	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1
Features		HEF4000B	HC(T)	AHC(T)	VHC(T)	LV-A(T)	CBT(D)	LVC	LV1T	NXS(B)	LSF
	Overvoltage Tolerant I/Os		•	•	•		•	•	•	•	•
	Schmitt Trigger Inputs	•	•	•	•			•	•		
	Low Threshold Inputs		•	•	•				•		
	TTL Inputs		•	•	•		•		•		
	Input Clamp Diodes	•	•								
	Power-Off Leakage Protection							•	•	•	•
	Open Drain Outputs		•	•				•	•	•	•
	Low Delay Isolation						•				

Low voltage families

Parameters	LV	LVC	LVT	ALVC	CBTLV(D)	AUP	AVC	AXPnT	CB3Q	AUP1T	XS3A	NXT
Supply voltage (V)	1.0 - 3.6	1.2 - 3.6	2.7 - 3.6	1.2- 3.6	1.0 - 3.6	0.8 - 3.6	1.2 - 3.6	0.9 - 5.5	2.3 - 3.6	2.3 - 3.6	1.4 - 4.3	1.08 - 3.3
Propagation Delay (TYP) (ns)	9	4	2	2	0.15	3.4	1	8	0.2	4	22	7 - 15
Output drive (mA)	+8	+24	-32, +64	+24	N/A	+1.9	+8	+12	N/A	±4	N/A	
Standby Current (μA)	20	20	120	40	10	0.9	20	4 .. 13	400	1.4 .. 3.5	0.7	
AEC-Q100 Grade	Levels 1	Level 1	Level 3	Level 1,3	Level 1	Level 1	Level 1	Level 1	Level 3	Level 1	Level 1	N/A

Features	LV	LVC	LVT	ALVC	CBTLV(D)	AUP	AVC	AXPnT	CB3Q	AUP1T	XS3A	NXT
Overvoltage Tolerant I/Os		•	•	•	•	•	•	•	•	•		
Schmitt Trigger Inputs	•	•	•	•			•		•	•		
Low Threshold Inputs	•						•	•	•	•	•	
Input Clamp Diodes	•									•		
Bus hold		•	•	•		•						
Power-Off Leakage Protection		•	•		•	•	•	•	•	•		
Source termination		•	•	•		•						
Open Drain Outputs	•	•					•		•			
Low Delay Isolation					•						•	

Design challenge #11:

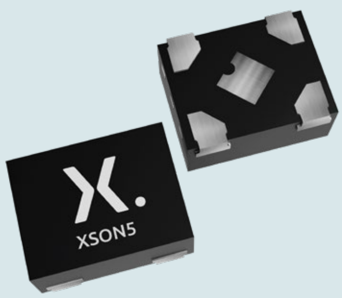
Overcoming the cost and engineering challenges when moving from leaded to leadless packages in space constrained applications such as camera

Nexperia Solution for Challenge #11:

For the increased space constrains Nexperia's MicroPak (XSON5, SOT8065) devices offer solutions. It is the World's first 5-pin mini logic package with Side Wettable Flanks. These flanks allow solder fillet to rise along the walls of the package and can be visually inspected using an inexpensive camera. Preceding leadless packages needed expensive X ray to enable such inspection. The centre pad has been enlarged to allow a via under pad. The pad-to-pad clearance has also been increased to enable routing to the centre pad on the top layer of the PCB. It features the same electrical specifications as the leaded alternative while offering significant space savings.

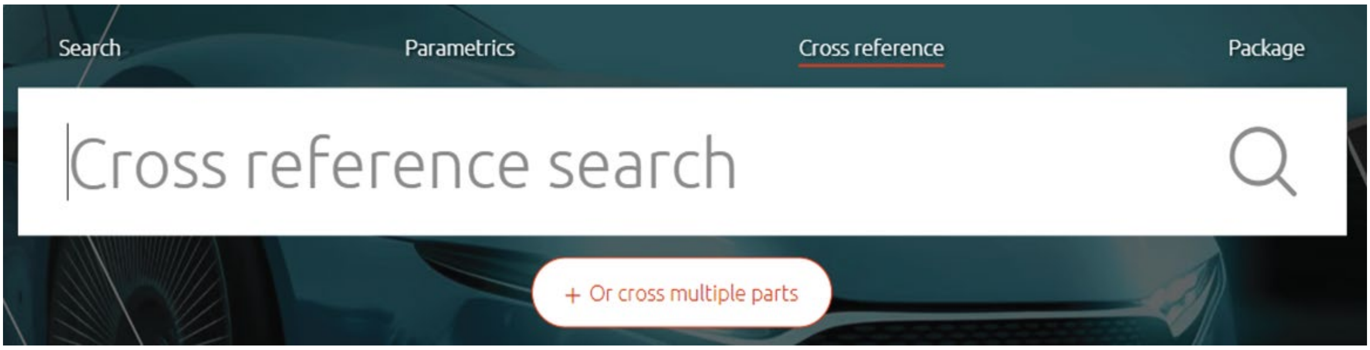
Nexperia's Sugested MicroPak (XSON5, SOT8065) packages

- Smallest leadless package that supports Automated Optical Inspection
- Breakthrough technology towards miniaturisation
- Includes families: HC(T), AHC, AUP, LVC, LVnT
- 1.1 mm x 0.85 mm x 0.47 mm
- Uses the same die as SOT353
- ~75% PCB area saving compared to SOT353
- Zero delamination, MSL 1
- Uniform 7 mm Sn layer on pad sides and bottom
- RoHS and dark green compliant



5. Recommended products

Nexperia offers a wide portfolio of discrete, analog and logic devices for camera systems. To find an equivalent to the used device please refer to the Nexperia website, cross reference search.



5.1 Power electronics

Product	Description	Key part numbers
Power input protection 1		
TVS and ESD protection devices		
TVS	SOD128, 600 W Transient Voltage Suppressor, Reverse standoff voltage range: 3.3-64V	PTVS16VP1UP-Q
	SOD128, 600 W Transient Voltage Suppressor, Reverse standoff voltage range: 3.3-64V, <185°C Temperature stability	PTVS16VP1UTP-Q
	SOD123W, 400 W Transient Voltage Suppressor, Reverse standoff voltage range: 3.3-64V	PTVS33VS1UR-Q
	SOD123W, 400 W Transient Voltage Suppressor, Reverse standoff voltage range: 3.3-64V, <185°C Temperature stability	PTVS33VS1UTR-Q
	DFN1006-2, Ultra Compact Transient Voltage Suppressor	PTVS4V5D1BL-Q, PTVS5V5D1BL-Q
Load switch and reverse battery protection		
Schottky Diodes	40V, medium power, low VF Schottky barrier rectifier in CFP package	PMEG4050E(T)P-Q, PMEG4030E(T)P-Q
	30V, medium power, low VF Schottky barrier rectifier in CFP package	PMEG3050(B)EP-Q, PMEG3030(B)EP-Q
P-channel MOS	LFPAK56, LFPAK33, MLPAK33 and DFN2020MD, 20-80V, P-channel devices	BUK6Y14-40P, BUK6Q12-40P
N-channel MOS	LFPAK33, 40V, N-channel device, R_{DSon} 3-15mOhm,	BUK9M3R3-40H, BUK9M4R3-40H, BUK9M7R2-40E, BUK9M9R1-40E, BUK7M8R0-40E, BUK7M10-40E, BUK7M12-40E
	LFPAK56D, 40V, Dual N-channel device, R_{DSon} 3-30mOhm	BUK9K13-40H, BUK9K6R2-40E, BUK9K6R8-40E, BUK9K8R7-40E, BUK7K6R2-40E BUK7K6R8-40E, BUK7K8R7-40E
	DFN2020MD-6, 40V, N-channel device, R_{DSon} 10-30mOhm	BUK9D23-40E, BUK6D23-40E, BUK7D25-40E, BUK6D30-40E,
	MLPAK33, 40V, N-channel devices, 4.6-7.5mOhm, Logic Level gate threshold	BUK9Q4R6-40H, BUK9Q7R0-40H, BUK7Q4R9-40H, BUK7Q6R0-40H, BUK7Q7R5-40H
	SOT457, 40V, N-channel device	PMN20ENA, PMN30ENEA
Bipolar transistors	Low voltage, leadless package, linear mode low V_{CEsat} devices	PBSS4310PAS-Q, PBSS4620PA-Q
Integrated load switch	5.5 V, load switch with precision current limit	NPS4053-Q100, NPS4001-Q100, NPS4069-Q100
Ideal diodes	1.5A Ideal Diode with Reverse Polarity Protection	NID5100-Q100

Product	Description	Key part numbers
Power Management 2		
N-channel MOS	LFPAK33, 40V/80V/100V, N-channel device, R_{DSon} 10-20mOhm,	BUK9M11-40H, BUK9M15-40H, BUK7M20-40H, BUK9M24-80L
	LFPAK56D, 40V/80V/100V, Half Bridge and Dual N-channel device	BUK9V13-40H, BUK7V4R2-40H, BUK9K13-40H, BUK9K49-80L
	SOT457, 40V, N-channel device, R_{DSon} 19mOhm and 23mOhm	PMN20ENA, PMN30ENEA
	MLPAK33, 40V/60V/80V, N-channel devices	BUK9Q4R6-40H, BUK9Q7R0-40H, BUK7Q4R9-40H, BUK7Q6R0-40H, BUK7Q7R5-40H, BUK9Q29-60E, BUK9Q14-80L
	DFN2020MD-6, 40V, N-channel device, R_{DSon} 20-30mOhm	BUK6D23-40E, BUK9D23-40E, BUK7D25-40E, BUK6D30-40E
Schottky Diodes	CFP3, 40V/60V/100V low V_f, low leakage current Trench Schottky barrier rectifier	PMEG40T30ER-Q, PMEG60T20ELR-Q, PMEG100T30ELR-Q
Step down (Buck) converter	SOT23-6, 4.5-40V V_{in}, 600mA Synchronous Buck converter	NEX40400-Q100
	QFN-12, 3.8-40V V_{in}, 2A/3A Synchronous Buck converter	NEX40402/3-Q100
	QFN-8, 6-100V V_{in}, 1A Synchronous Buck converter	NEX40101-Q100
Zener diodes	CFP3, 3-12V, 400mA, 5% tolerance	HPZR-C12-Q
	DFN1006(BD)-2, 3-12V, 200mA, 2% and 5% tolerance	BZX884 series, PZU884LS-Q series
Power distribution		
Signal MOSFET	SOT363, 30V and 60V dual and complementary pair Trench MOSFETs	NX3008CBKS
	SOT323, 30V and 60V, N-channel Trench MOSFET	NX3008NBKW
	DFN1010B-6, dual N-channel Trench MOSFET	PMXB360ENEA
	DFN2020MD-6, >30V, dual N-channel Trench MOSFET	PMDPB56XNEA
Signal BJTs	SOT ~300mW, 20V – 100V power bipolar transistor	BC817K-16, BC817K-25, BC54-16PA-Q, PBSS4160T-Q, PBSS4140U, PBSS4160U, PBSS8110D, PBSS4021NX-Q, PBSS4330X
	DFN ~300mW, 10 - 100V power bipolar transistors	BC54PA-Q, BC54-10PA-Q, BC54-16PA-Q, PBSS2515MB, PBSS2540M, PBSS2540MB, PBSS4260QA, PBSS4310PAS-Q, PBSS4620PA-Q
Shunt regulators	SOT23, 3-terminal adjustable shunt regulators	TL431AFDT-Q and TLVH431N family
High side switch	40V, 200mΩ Smart High Side switch	NPS6210
Integrated load switch	5.5V, 2A, 55mΩ, TSOP6 and HWSON6 package	NPS4053GV-Q100 and NPS4053GH-Q100
LDO	40V/300mA/150mA general purpose LDO with 5μA ultra low I_q	NEX90530BPA-Q100, NEX90515BPA-Q100
	40V/300mA/150mA tracking LDO with 5μA ultra low I_q	NEX91x30-Q100, NEX91x15-Q100
	40V/300mA/150mA antenna LDO	NEX92x30-Q100
	40V/70mA tracking LDO, SCT595-5 and SOT23-5 package	NEX91207DF-Q100, NEX91207DE-Q100

5.2 Signal electronics

Product	Description	Key part numbers
Communication interface 3		
ESD for CAN and IVN	SOT package, 3-17pF, 30kV protection for 12V board net	PESD2IVN27T-Q, PESD2IVN27U-Q, PESD2CANFD24UT-Q, PESD2CANFD24UU-Q
	DFN package, 3.5-10pF, 30kV protection for 12V board net	PESD2CANFD24UQB-Q, PESD2CANFD24UQC-Q
	SOT package, 3.9-10pF, 30kV protection for 24V board net	PESD2CANFD36UT-Q, PESD2CANFD36UU-Q
	DFN package, 3.5-10pF, 30kV protection for 24V board net	PESD2CANFD36LQC-Q, PESD2CANFD33UQB-Q, PESD1CANFD24LS-Q
	SOT23, 8pF, 30kV protection for 48V board net	PESD2IVN48T-Q, PESD2CANFD54VT-Q, PESD2CANFD60VT-Q, PESD2CANFD72VT-Q
ESD for Ethernet (ESD_1 from Fig. 26)	SOT23, 1-3pF, 30kV protection, 24V standoff voltage	PESD2ETH1GXT-Q
	DFN1006BD-2, 1.2-1.8pF, 30kV protection, 24V standoff voltage	PESD1ETH1GXLS-Q
ESD for Ethernet (ESD_1 from Fig. 26)	DFN1006-2, <0.6pF, >10kV protection	PESD18VF1BBL-Q, PESD24VF1BBL-Q, PESD30VF1BBL-Q, PESD5V0C1BLS-Q
ESD for 10Base-T1s Ethernet	DFN and SOT package, high trigger voltage, low capacitance ESD protection up to 18kV	PESD2ETH10T-Q, PESD1ETH10L-Q, PESD1ETH10LS-Q
High speed multimedia ESD protection	SuperSpeed USB 3.2 at 10 Gbps, HDMI, DisplayPort, external Serial Advanced Technology Attachment (eSATA), Low Voltage Differential Signaling (LVDS), and Gigabit Multimedia Serial Link (GMSL) Serializer/Deserializer (SerDes)	PESD4USB3U-TBS, PESD4USB3B-TTS, PESD4USB5U-TTS PESD4USB5B-TBS
Signal processing 4		
Inverters/Buffers/ Logic gates/ Registers	AHC(T) product family, V_{cc} 2-6V (4.5-5.5V)	74AHC08BQ-Q100
	HC(T) product family, V_{cc}2-6V (4.5-5.5V)	74HC2G08DC-Q100
	LVC product family, V_{cc} 1.2-3.6V	74LVC126ABQ-Q100
	AUP product family, V_{cc} 0.8-3.6V	74AUP2G80DC-Q100
	HCS product family, V_{cc} 2-6V, true Schmitt trigger inputs	74HCS594BQ-Q100
	XSON5 – smallest leadless package with AOI	74AHC1G04GZ-Q100
Translators	LVC product family, V_{cc} 1.2-5.5V	74LVC1T45GM-Q100
	AVC product family, V_{cc} 0.8-3.6V	74AVC1T45GW-Q100
	NXU product family, fixed direction, dual supply	NXU0104GU12-Q100
	HC(T) product family, V_{cc} 2-6V (4.5-5.5V)	74HC1G66GW-Q100
	LSF product family, bi-directional translators with auto-direction sensing	LSF0101GW-Q100
	NXS product family, bi-directional translator with auto-direction sensing with signal acceleration on rising edge	NXS0506GU-Q100
	NXB product family, bi-directional translator with auto-direction sensing with signal acceleration on rising and falling edge	NXB0108BQ-Q100
Switches/Multiplexers	SP8T-Z and SP4T-Z analog switches	NMUX1308BQ-Q100
	Single-pole double-throw analog switches	XS5A1T4157-Q100
Resistor equipped transistors (RETs)	SOT23/SOT323/DFN1412D-3/DFN1110D-3/DFN1006B-3 50V, 100mA single NPN RETs, various resistors	PDTC143XQB-Q
	SOT23/SOT323/DFN1412D-3/DFN1110D-3/DFN1006B-3 50V, 100mA single PNP RETs, various resistors	PDTA144WMB

6. References

Nexperia handbooks

MOSFET and GaN FET application handbook
ESD Application Handbook
Bipolar Junction Transistor (BJT) Application Handbook
Diode fundamentals, characteristics and applications
Logic product features and application insights

Application notes

IAN50007 - Conducted battery line transients
AN50001 - Reverse battery protection in automotive applications
AN50007 - Applying ISO standard conducted transients to MOSFETs in 12 V, 24 V and 48 V systems
AN50019 - Thermal boundary condition study on MOSFET packages and PCB substrates
AN50020 - MOSFETs in Power Switch applications
AN90003 - LFPAK MOSFET thermal design guide
AN90011 - Half-bridge MOSFET switching and its impact on EMC
AN90023 - Thermal performance of DFN packages
AN90024 - Resistor Equipped Transistors (RETs): Key parameters and application insights
AN90031 - Zener diodes - physical basics, parameters and application examples
AN90033 - Bidirectional multi-voltage level translator applications using Nexperia's LSF010x auto-sense devices
AN90034 - Nexperia Precision Electrothermal models in SPICE and VHDL-AMS for Power MOSFETs
AN90039 - ESD protection devices for automotive Ethernet applications (100Base-T1, 1000Base-T1)
AN90052 - Nexperia load switch ICs compared to discrete solutions
AN10441 - Level shifting techniques in I²C-bus design
AN11119 - Medium power small-signal MOSFETs in DC-to-DC conversion
AN11550 - Performance of Schottky rectifier in CFP15 package in low power adapter
AN11882 - High-speed interfaces - ESD protection and EMI filtering
TN90007 - Evaluation of junction temperature and thermal stacks using the virtual junction

Other collaterals

Whitepaper - TVS Diodes
Whitepaper - Side-Wettable Flanks
Whitepaper - RET devices
Brochure - CFP Schottky rectifier
Brochure - ESD Protection Applications
Brochure - Nexperia ESD Automotive Application Guide
Leaflet - LFPAK56D factsheet
Leaflet - DFN2020MD-6
Leaflet - Small signal MOSFETs for Automotive applications
Leaflet - Automotive DFN package factsheet
Leaflet - Electronics power management load switch
Leaflet - Nexperia ESD Protection for automotive CAN-FD
Leaflet - Nexperia Automotive Ethernet leaflet ESD Protection Factsheet
Leaflet - Nexperia packages
Leaflet - Logic X2SON packages
Webinar - Power Rectifier Webinar Series
Blog - Consider Low V_{CEsat} BJTs for High Power Supply Efficiency
Blog - Need a Stable Voltage or Current Source? Sometimes it Pays to be Discrete!

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