Automotive

ADAS

Radar 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).

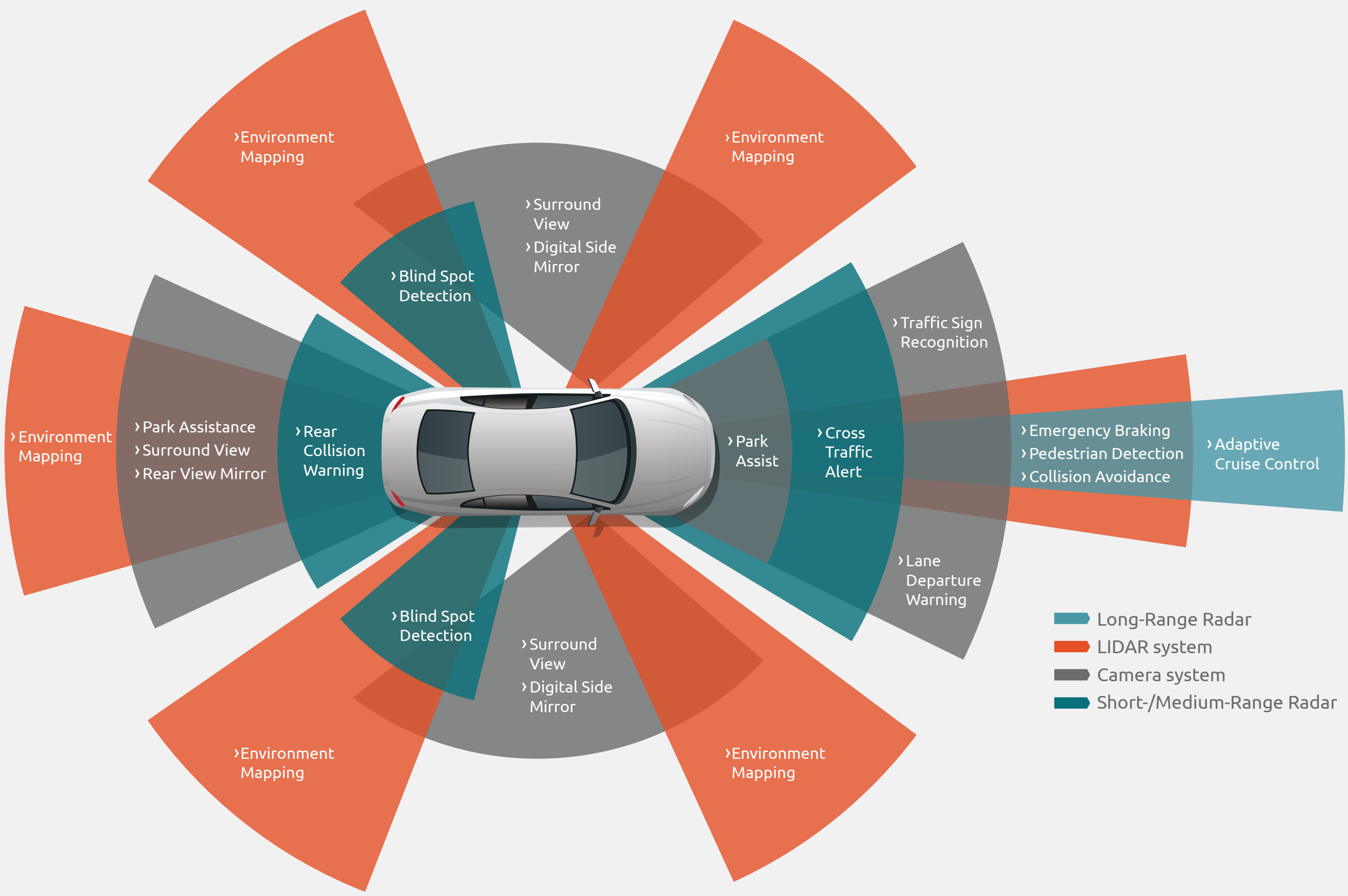


Fig. 1. ADAS sensors, their function and sensitivity field.

Radar sensors

Radar is an acronym for **Ra**dio **D**etection **A**nd **R**anging. Radar sensors transmit electromagnetic waves towards an object and analyse the received wave reflected back by it. These sensors consist of a transmitter that generates and transmits the electromagnetic wave and a receiver that receives the reflected wave. Signal processing functions extract target properties from the received signal. Automotive radar sensors can obtain distance, speed, and information about the object's direction by analysing the properties of the reflected waves.

Automotive radar sensors are widely used in ADAS. They have certain benefits, which can be divided into economic and technical benefits.

Economic benefits

- Radar manufacturing costs are comparable to camera systems but significantly lower than those of lidar sensors. Since the introduction of radars, their costs have decreased drastically, mainly due to advances in semiconductor technology and sensor packaging costs
- Radar sensors were the first sensors introduced amongst the ADAS systems and have a broad supplier base present in all the key regions, including AMEC, EMEA, China, Japan and Korea

Technical benefits

- Radar sensors provide robust performance under low light or adverse weather conditions such as rain or dust
- Radar sensors deliver a longer detection range than camera systems or lidar sensors
- Hidden sensor integration in car bodies is only possible with radar sensors. For a complete 360 degree view of the vehicle, multiple sensors need to be integrated within the vehicle, and only radar sensors provide this possibility without affecting vehicle aesthetics

Key requirements	Radar	Camera	Lidar
Depth Resolution	Superior	Average	Superior
Depth Range	Superior	Average	Superior
Adverse Weather	Superior	Average	Average
Low-light Performance	Superior	Average	Superior
Velocity	Superior	Inferior	Average
Cost	Superior	Superior	Average
Angular Resolution	Average	Superior	Superior
Traffic Signs	Inferior	Superior	Average
Object Edge Precision	Inferior	Superior	Superior
Lane Detection	Inferior	Superior	Average
Color Recognition	Inferior	Superior	Inferior

● Superior ● Average ● Inferior

2. Application description

Radar sensors can be categorized into four main types:

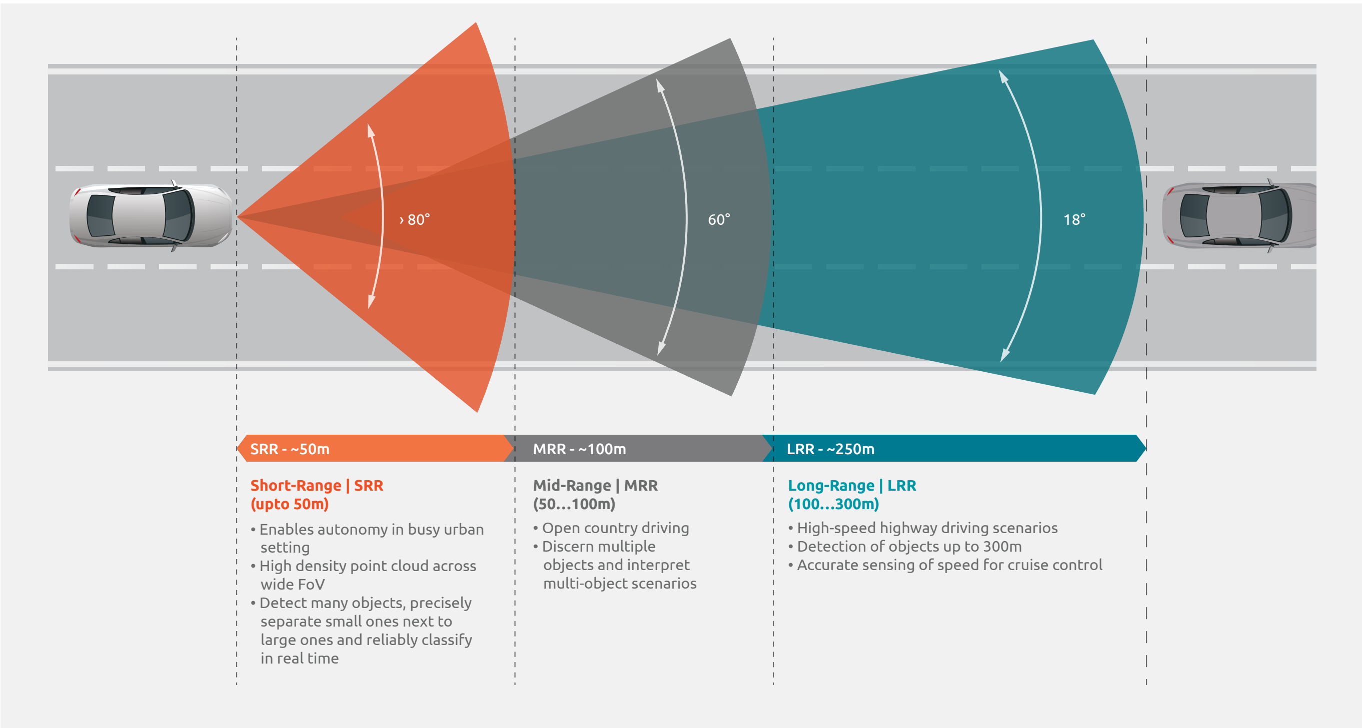
- In-Cabin Radars
- SRR – Short-Range Radar
- MRR – Mid-Range Radar
- LRR – Long Range Radar

- In-cabin radars are gaining traction in the market and are part of the vehicle's comfort features. With new user safety standards, these systems are becoming more prominent in present-day vehicles. The key applications for these radars are driver/occupant, detection/monitoring (DMS/OMS) and Seat Belt Reminders (SBR)

- Short-Range Radar systems are generally used for applications when the vehicle is moving slowly or an obstacle is located near it. These applications could be blind spot detection (BSD) or lane change assist (LCA)

- Both Short- and Mid-Range Radar sensors can be placed on all four corners and sides of the vehicle. This is called a corner radar and can detect obstacles or pedestrians before they are visible to the driver and deploy automatic emergency braking (AEB)

- Long Range Radars are most commonly placed in the front section of vehicles as they detect traffic changes from farther distances ahead



Deployment of various radars in a vehicle

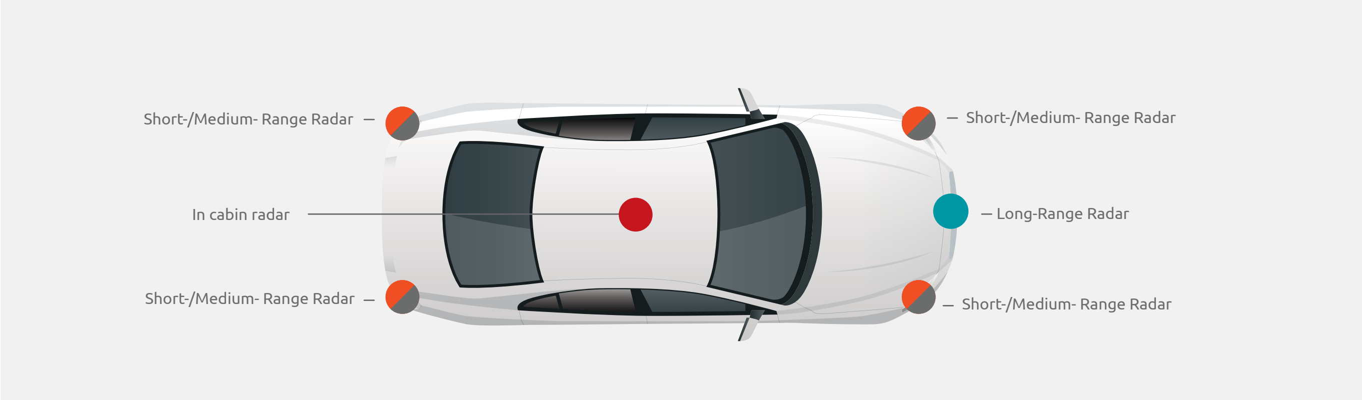


Fig. 2. Radar sensors: sensitivity field, functions and positioning around the vehicle.

3. Application trends

Bandwidth evolution

The frequency bands of Radars have evolved since the inception of Automotive Radars. Initially, radars operated at a frequency of 24 GHz before moving to the 77 GHz frequency band. 77 GHz frequency band offers multiple advantages over 24 GHz:

› Larger available bandwidth & better resolution

The 77 GHz frequency band for automotive radar applications uses the frequency range from 76 to 81 GHz with a bandwidth of over 4 GHz as compared to a bandwidth of 200 MHz available for automotive radar applications at 24 GHz. This wide bandwidth increases range resolution and accuracy. Range resolution is defined as the ability to separate two closely spaced objects, whereas range accuracy means the accuracy in measuring the distance of a single object. Since range resolution and accuracy are inversely proportional to the sweep bandwidth, a 77 GHz radar sensor can achieve 20x better performance in range resolution and accuracy compared to a 24 GHz radar.

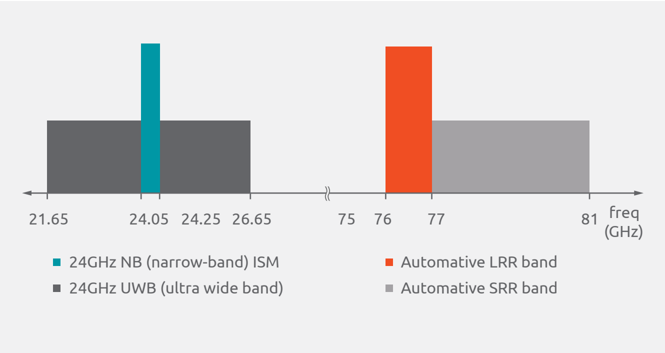


Fig. 3. Bandwidth expansion with transition from 24 GHz to 77 GHz radar sensors.

Radio frequency is inversely proportional to velocity resolution and accuracy. Velocity resolution is defined as the radars ability to distinguish between objects moving at different speeds whereas velocity accuracy refers to how precisely a radar can measure the actual velocity of an object. Both are critical parameters to track moving objects. Therefore, a higher frequency leads to better velocity resolution and accuracy. Compared to 24 GHz sensors, the 77 GHz sensor improves velocity resolution and accuracy by 3x. Velocity resolution is critical for park-assist applications where the vehicle must be manoeuvred accurately at slow speeds.

This enhanced resolution also improves the detection and avoidance of big objects, like cars, and allows the avoidance of smaller ones, like pedestrians. It also provides drivers with better object resolution in situations with poor visibility.

› Smaller form factor

77 GHz radar systems have a much smaller form factor in comparison to 24 GHz radars. As the relationship between the antenna size and the frequency is linear, the wavelength of 77 GHz signals is one-third of that of a 24 GHz system, therefore area needed for a 77 GHz radar antenna is one-ninth the size of a similar 24 GHz antenna.

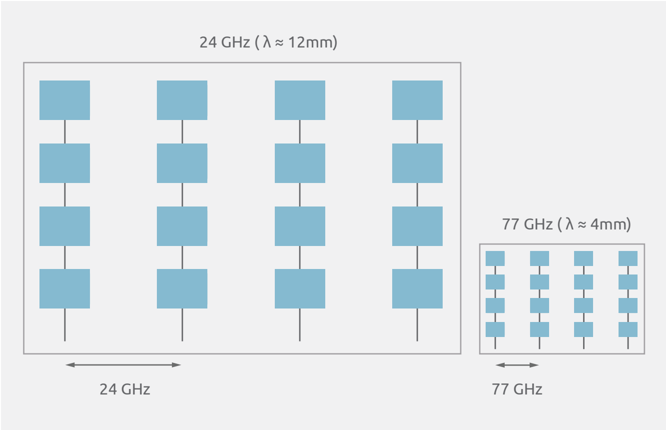


Fig. 4. Space savings with transition from 24 GHz to 77 GHz radar sensors.

› Higher power levels:

77 GHz radars have higher permitted transmit power levels. The Effective Isotropic Radiated Power (EIRP) for automotive radars in the 77 GHz is 55 dBm (-3 dBm/MHz). For 24 GHz radars the peak limit is only 20 dBm EIRP. These high power levels enables the radars to cover front long range applications like adaptive cruise control.

Introduction of 4D imaging radars

Recently new types of radars have been introduced in the automotive market and is commonly known as 4D Imaging Radar systems. Conventional radar systems are trained at scanning roadways across the horizontal plane and identifying 3 Dimensions, namely, Distance, Direction and relative Velocity of the object. But the 4D Imaging Radars have the ability to capture another dimension i.e. the Vertical dimension.
With both the horizontal and vertical data information, these radars can detect many different reflection points, which, when mapped, can begin to resemble an image.

4D imaging radars are important in the development of advanced driver-assistance systems (ADAS) for some Level 2 and 3 functions and are a key enabler for Level 4 and 5 automated vehicles as they offer excellent detection of both moving and stationary objects from greater distances and with better accuracy than traditional radar sensors.

In the schematic below, we can compare various ADAS sensors in terms of their ability to capture various dimensions of an object. Conventional radars are the right technology to detect the distance and speed of objects around the vehicle, whereas 4D Imaging Radars significantly improve the angle and classification of objects.

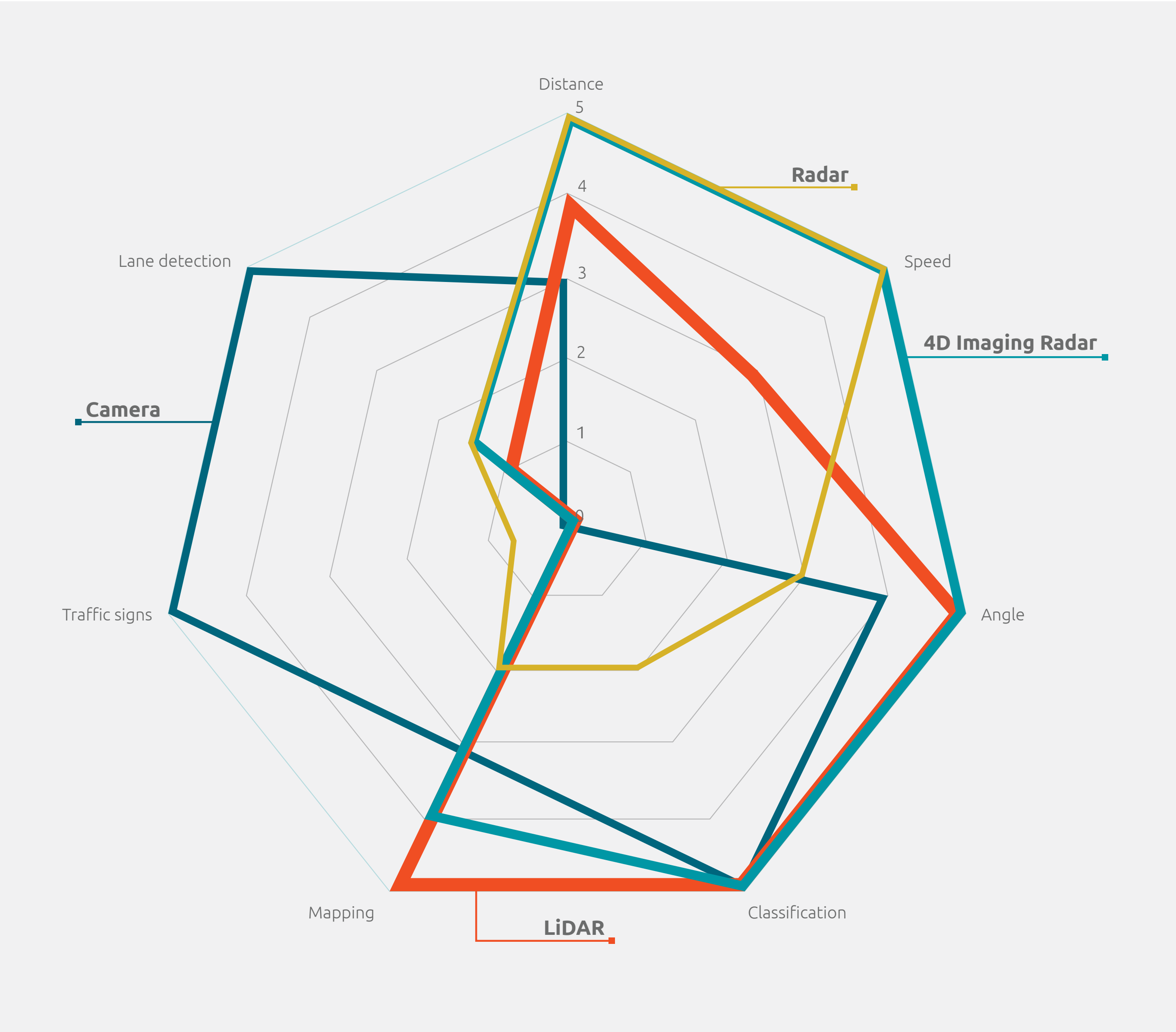


Fig. 5. ADAS systems spider chart

4. Application Overview

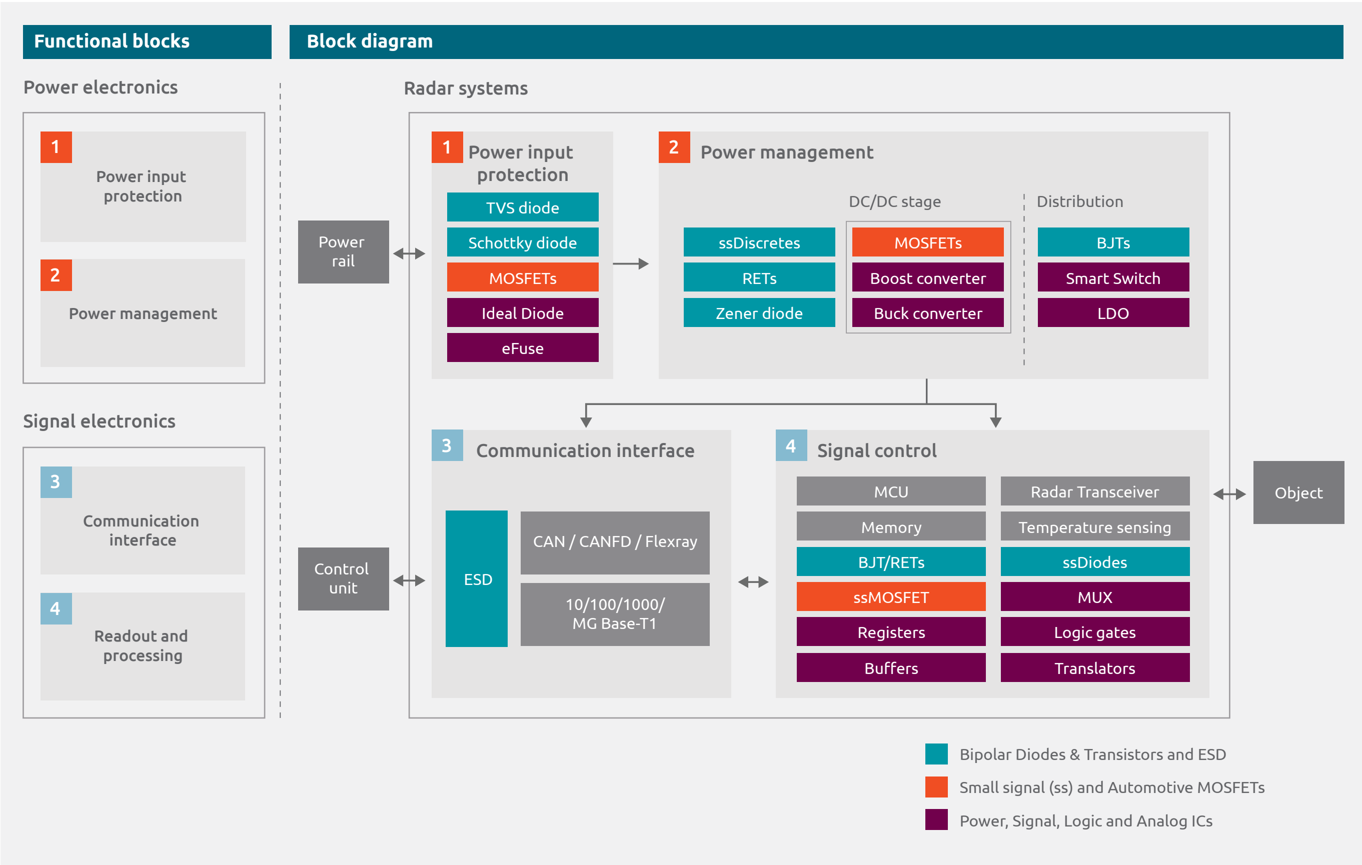


Fig 6. SRR/MRR/LRR block diagram.

The block diagram above gives an overview of the devices that feature in a generic radar system. 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 interfaces the radar 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 radar from external disturbances, limit power consumption when the radar is not used, and maintain outer system functionality if the radar malfunctions.

2 The Power Management block contains means for transforming the incoming voltage to a level that is suitable for the rest of the components within the radar. This is achieved via switching buck and boost converters in integrated circuits, but can also be designed via discrete MOSFETs. LDOs then refine these voltages further. Smart switches can limit the power towards circuits that are not used at a given time. Other circuits like voltage monitoring or wake-up circuits can be realised by small signal MOSFETs, BJTs and diodes.

3 The Communication Interface block consists of fast CAN or Ethernet PHYs and the accompanying ESD to ensure reliable communication with the controlling unit.

4 Finally, the Signal Control block contains the MCU, Memory, and Radar transceiver itself. Logic devices and small signal devices can implement accompanying logic, interfacing with established blocks, and additional safety layers.

A more detailed picture of the circuits employed is provided in Figure 7 on the next page.

Schematic with Nexperia product placements

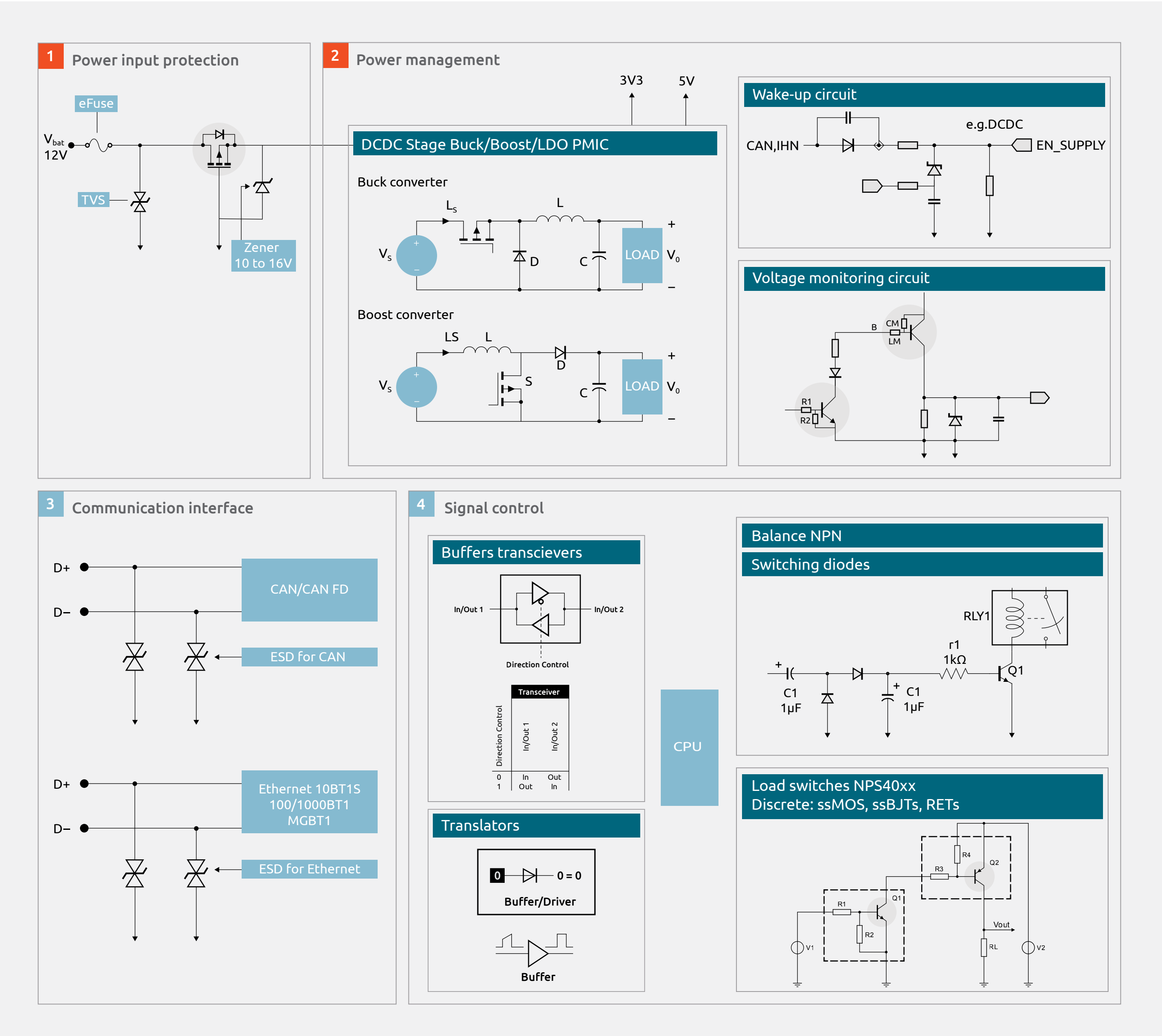
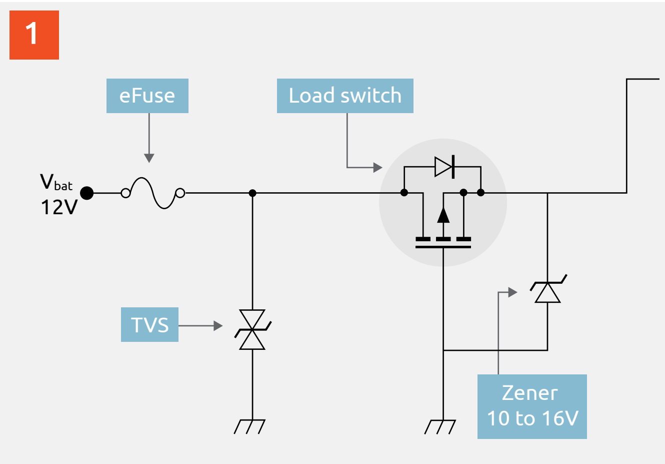


Fig. 7. Generic radar schematic with Nexperia product placements

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

5. Design challenges, solutions and Nexperia portfolio

5.1 Power input protection



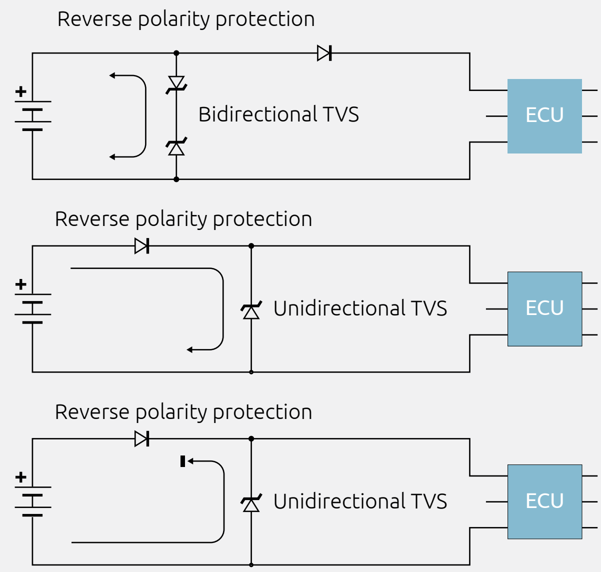


Fig. 8. Current flow for positive and negative pulses with bidirectional and unidirectional TVS

Design challenge #1:

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

Nexperia Discrete Solution to Challenge #1:

For a vehicle's board net of 12V, 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.

TVS diodes [1,3] 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.

Figure 8 shows how the negative pulses can be tackled. For cost effective implementations, such as radar sensors, a unidirectional TVS with a high-voltage diode is an elegant solution, but Schottky diodes or MOSFETs can also be used. The highest negative pulse usually considered is the ISO7637-2 Pulse 3a with a -150 V pulse.

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

CFP Package	Voltage	10/1000µs Power Rating
SOT-23	3 – 26 V	24 – 40W
SOD123W	3.5 – 64 V	400W
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 64V
- Automotive qualified up to junction temperature of 185 °C

Design challenge #2:

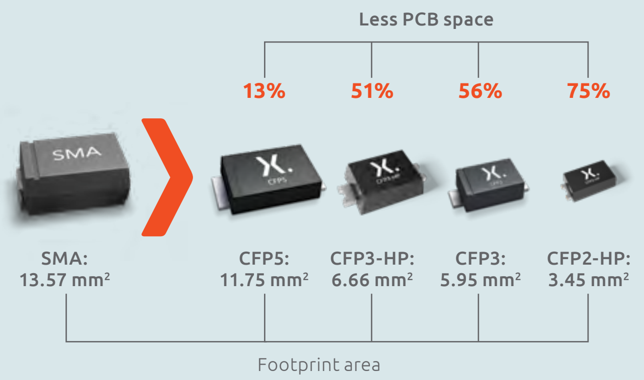
Protecting the radar electronics from negative overvoltages that can happen if the battery is connected in reverse.

Nexperia discrete solution for design challenge #2

To protect from these, an additional switch can be added in the protection circuit. The realization of the switch can be with a diode, Schottky diode, single N-channel MOSFETs or a P-channel MOSFET[5]. Specifically for Radar applications, 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 radar application, the switch is predominantly realized with a single Schottky diode. The advantage of this approach is easy design-in and cost effectiveness. The losses caused by the voltage drop across the device can be neglected due to the low power consumption of radars.

Nexperia offers planar Schottky diode technology with very low forward drop voltage. The Clip-bonded FlatPower (CFP)[12] 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.

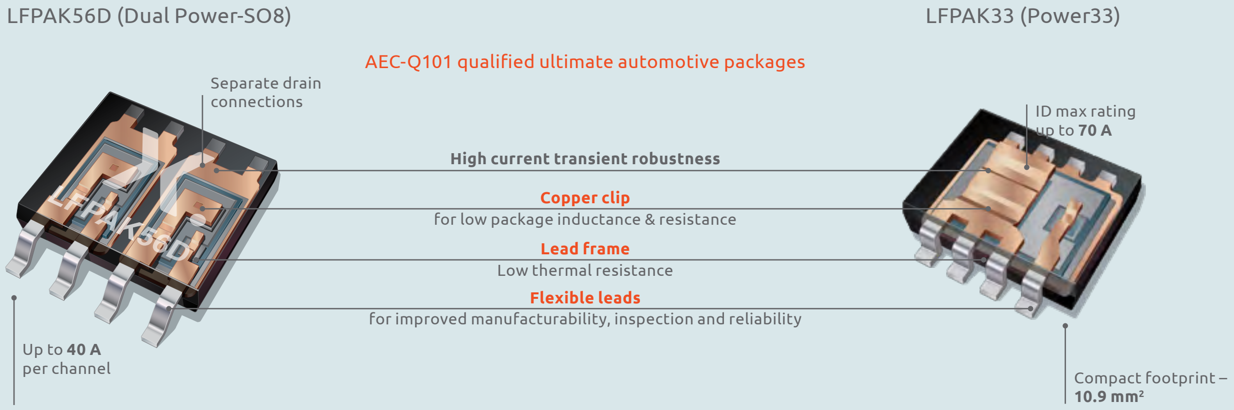
Suggested Nexperia Schottky diodes



- Solid copper clip for high thermal performance and power dissipation
- Reduced package inductance for improved switching behavior
- High reliability (2 x AEC-Q101, Board Level Reliability compliance)
- Free from delamination
- Junction temperature up to 175 °C
- Small, thin and light design
- Optimized lead form ensuring uniform solder joints for maximum flexibility in AOI

Recommended MOSFET packages for reverse battery protection as well as dc/dc converters (see Power Management section) are Nexperia's range of LFPAK33 (3x3mm leaded, copper clip, BUK9Mxxx) and LFPAK56D (5x6mm dual, leaded, copper clip, BUK9Kxxx[6]) packages and the newly introduced MLPAK33 (3x3mm leadless, BXK9Qxxx) 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 (2x2mm leadless, BUK6Dxxx or PMPBxxx) packages can be considered because of their good thermal performance [5]. 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 [7]. 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[8]. Nexperia's precision electrothermal models allow for making thermal considerations easier [9]. The packages with 'gull wing' leads are exceptional for environments that have high-temperature oscillations to achieve high board-level reliability. As radars are mounted externally, they will 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 leadless package types [10].
A comprehensive guide to MOSFETs can be found in the Nexperia MOSFET handbook [11].

Suggested Nexperia leaded MOSFETs



Suggested Nexperia micro-leaded MOSFETs

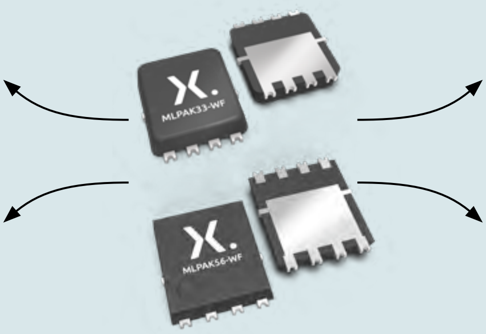
Automotive quality

› 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)

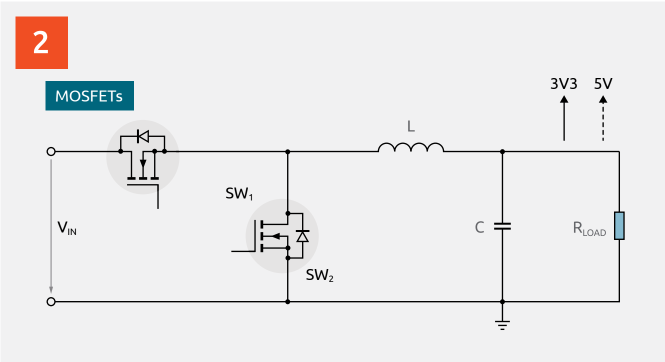
High power density

› Low $R_{DS(on)}$
  - ≥ 1mΩ in MLPAK56-WF
  - ≥ 2mΩ in MLPAK33-WF

› High current capability
  - ID max < 71A

› Low thermal resistance
  - Rch (j-mb) max > 1.54 K/W for MLPAK56-WF
  - Rch (j-mb) max > 2.5 K/W for MLPAK33-WF

5.2 Power management



Design challenge #3:

Stabilizing and converting the incoming voltage to a level suitable for the rest of the sections of the radar system. The incoming voltage can be from a 12V or 48V battery. The voltage can be relatively unstable because of the long lines and variety of loads and sources connected to it.

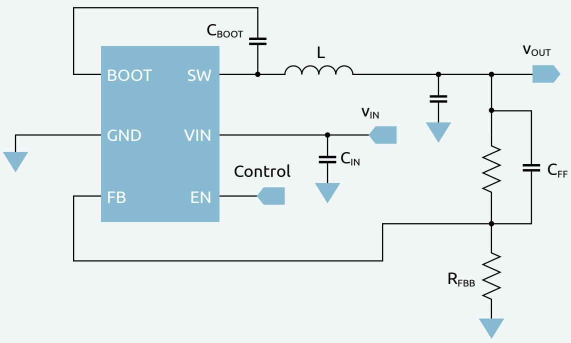
Nexperia integrated solution for challenge #3:
Voltage conversion can be achieved by a dedicated switching IC with internal devices. Such is the NEX40400-Q100 shown in the figure below within its application schematic. These devices have a wide range of input voltage capability in a small package. Further, they have low standby current for low battery usage and they are also EMI friendly and easy to design in.

MOSFETs can also be used as a local converter to 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 [15], 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 once again the DFN2020, LFPAK33, LFPAK56D and MLPAK33.

Contrary to the MOSFETs for reverse battery protection, 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) and L (T12 technology) for example: BUK9V13-40H or BXK9Q14-80L.

Suggested Nexperia integrated converter NEX40400-Q100

- 4.5V to - 40V wide input voltage range
- 600mA continuous output current
- 60uA standby, 1uA shutdown current
- 1.05MHz and 2.1MHz fixed switching frequency
- 1% output voltage accuracy
- Short circuit protection with Hiccup mode
- Frequency foldback at a high conversion ratio and low drop-out
- PFM mode for good light load efficiency
- Forced PWM mode for small output ripple
- Spread spectrum for better EMI
- Support startup with pre-biased output
- Internal compensation
- Precision Enable
- TSOT23-6 package

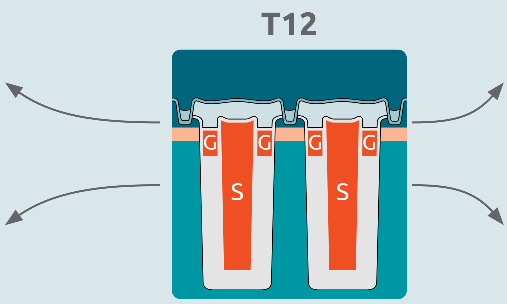


Suggested Nexperia T12 technology MOSFETs

Lower resistance per die area with soft and efficient switching performance (80V/100V)

High Silicon robustness
- Split gate technology
- High fault condition tolerance
- Avalanche Ruggedness

High power density
- Low $R_{DS(on)}$ > 12mΩ*
- High ID max
- Low $R_{th(j\text{-}mb)}$



Space saving LFPAK packages
- High manufacturability
- LFPAK33 and LFPAK56 Dual options for design flexibility
- High mechanical robustness
- High reliability

Ease of Use
- Soft-switching for improved EMI performance
- Efficient switching to reduce switching losses

However, to compare available MOSFETs effectively, engineers should perform their own double pulse testing (illustrated in Figure 10) to find a device with the best efficiency and switching behavior ratio. More information can be found in Nexperia Application Note AN90011 [17].

Nexperia discrete solution #2 for challenge #3

The freewheeling MOSFET can be replaced by a switching diode [18], as can be seen in Fig. 9. 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 [19].

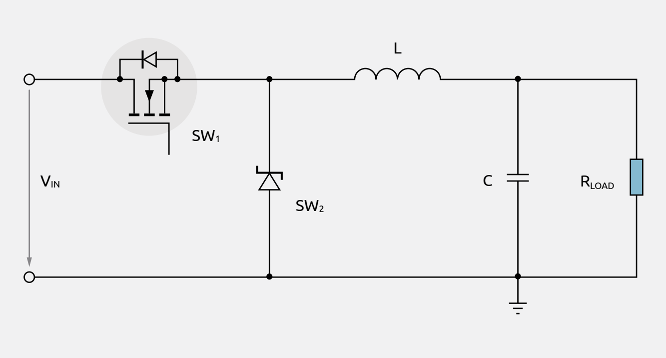


Fig. 9. Asynchronous buck converter with Schottky diode.

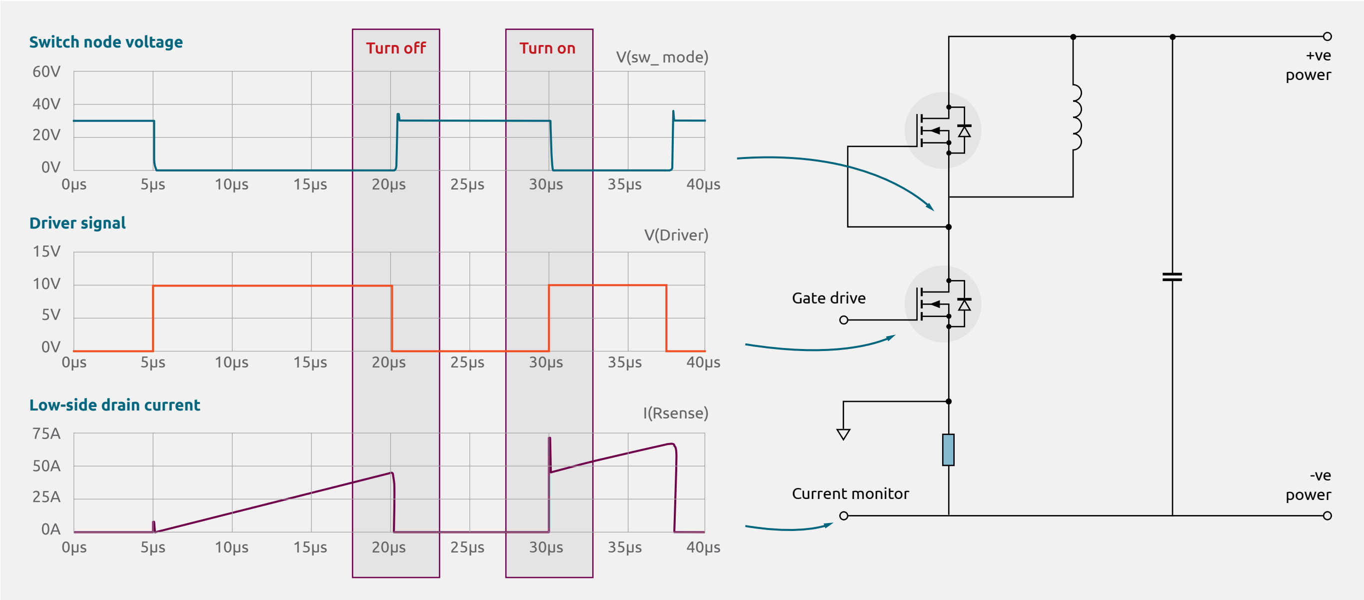


Fig. 10. Double pulse testing of power MOSFET devices; waveforms (left) and circuit (right).

Design challenge #4:

Protecting the radar system after the dc/dc converter from overvoltages, at lower voltages and power levels.

Nexperia solution for challenge #4

Zener diodes can also be used on voltage rails to protect from overvoltage transients [20]. 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. Zener diodes can be selected from Nexperia's clamping and protection range, product numbers starting with PZU.

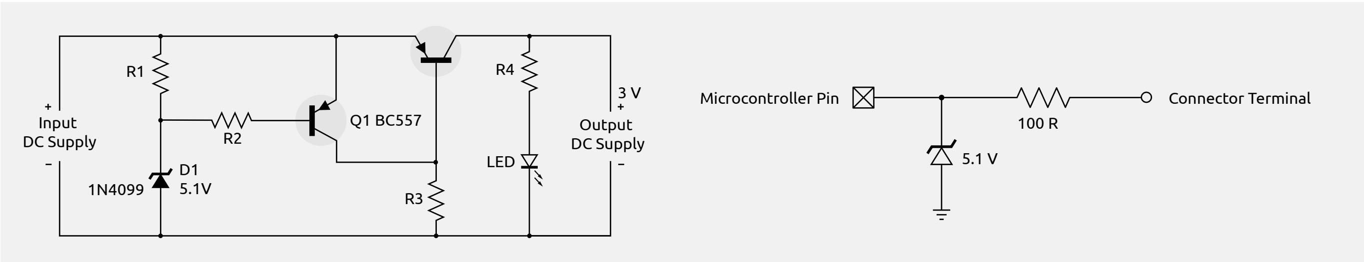


Fig. 11. Overvoltage protection for the microcontroller using Zener diodes.

Design challenge #5:

The next step in voltage conversion is achieving the voltage levels necessary to drive the core of the microcontroller in charge of the radar ECU. This step can generally be achieved by two different means: switching converter and regulated voltage drop.

Nexperia discrete solution #1 for challenge #5:

As the power levels for this step are quite low a switching converter can be realized using conventional small signal MOSFETs [15] or integrated power management circuits.

The MOSFETs used can be N-channel or a matched pair of P- and N-channel MOSFETs. The MOSFETs can be of the previously mentioned DFN types, however, they can also be realized with traditional packages. As the voltage is already converted and regulated to 3.3V or 5V before this conversion step is also shielded from external disturbances, the MOSFETs employed here can be of lower voltage rating: 20V or 30V. An example switching solution is depicted in Fig. 12. The MOSFETs utilized can be of very low size, packed in a DFN2020 (2x2mm) package detailed below and in the leaflet [21].

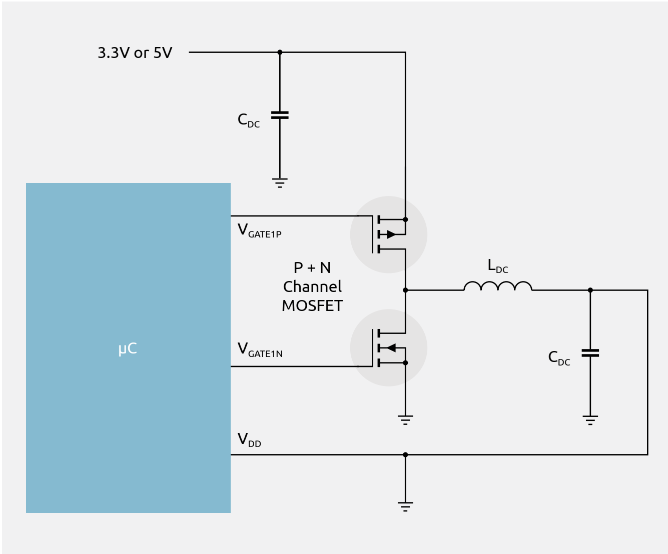
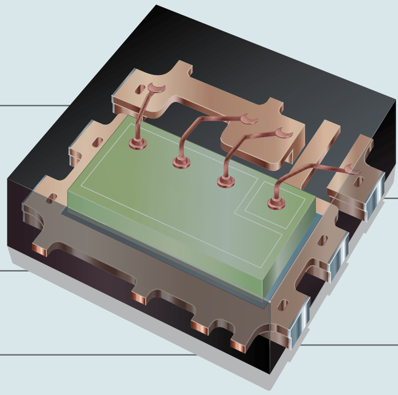


Fig. 12. Microcontroller voltage conversion with P- and N- channel MOSFETs.

Suggested Nexperia Package: DFN2020



Nexperia discrete solution #2 for challenge #5:
Nexperia's low V_{CEsat} portfolio is well-suited for achieving a regulated low voltage drop for the same purpose[23]. The figure below depicts suggested product families with their current and voltage ratings and packages.

Fig. 13 shows the realisation of the regulated voltage drop using a BJT. In addition to the transistor, resistors, and a reference shunt voltage regulator are needed.

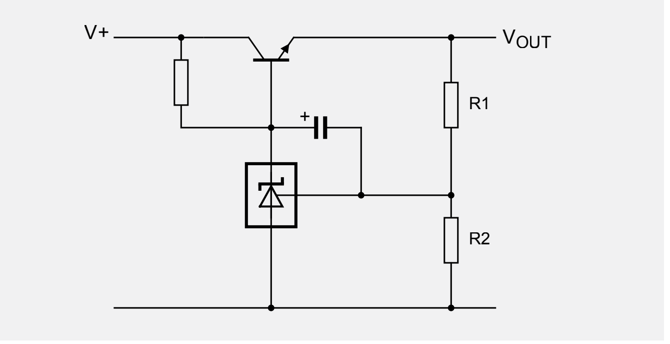
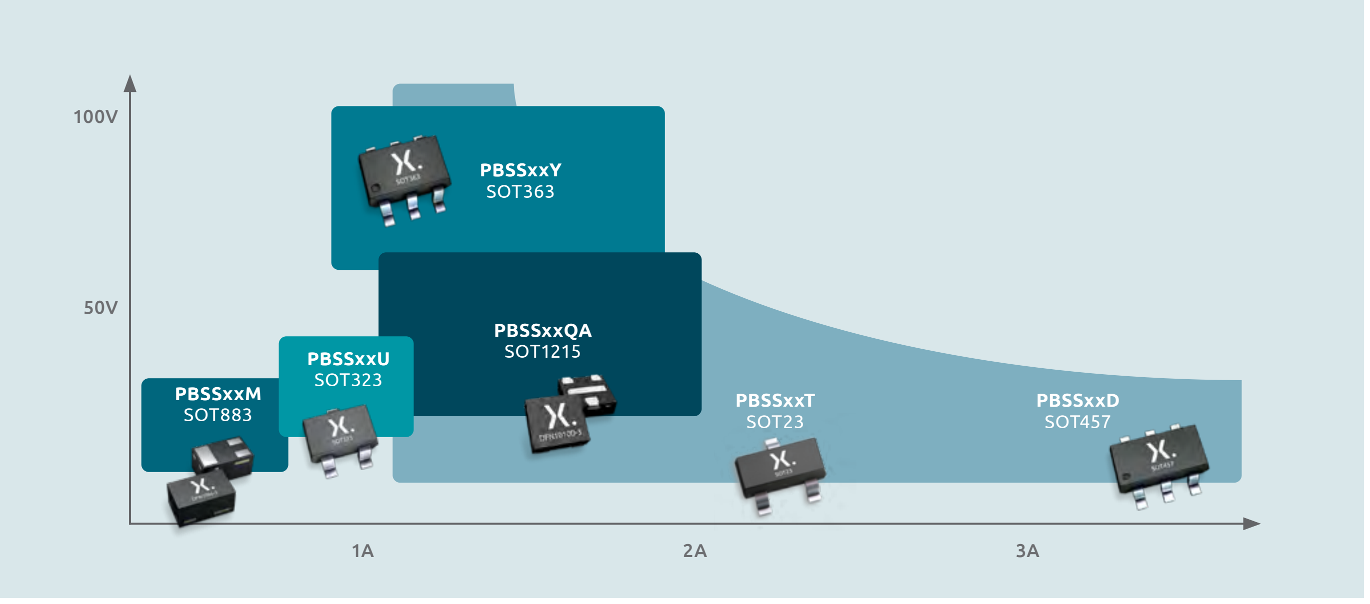


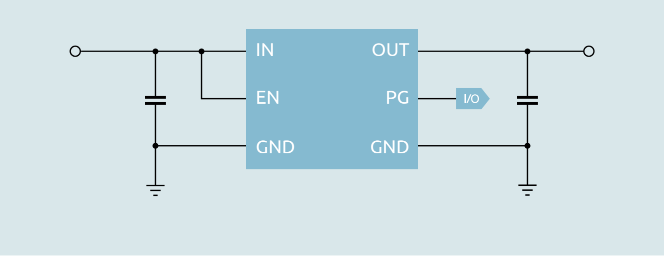
Fig. 13. Regulated voltage drop realisation with a discrete BJT.

Suggested low VCEsat BJT packages



Nexperia integrated solution for challenge #5:
On the other hand, a different solution is to employ Low DropOut (LDO) regulators. Nexperia offers 150mA (NEX90515-Q100) and 300mA (NEX90530-Q100) LDOs that feature low quiescent current (typical 5uA) and a wide input voltage range of up to 40V with up to 45V transient voltage. 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 communications port that is not used), and a Power good pin, that can indicate a potential short circuit in the load.

Suggested Nexperia LDOs: NEX90530-Q100/NEX90515-Q100



Design challenge #6:

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.

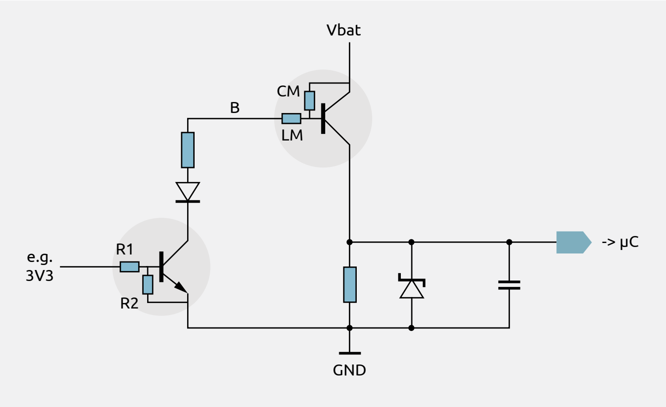


Fig. 14. Voltage monitoring circuit using RETs and Zener diodes.

Nexperia solution for challenge #6:

Voltage monitoring can be achieved using discrete components. In the case illustrated in Fig. 14, 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 [29, 25] and RETs [26, 27].

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. Fig 15, a simple OR circuit using small signal switching and Schottky diodes is proposed.

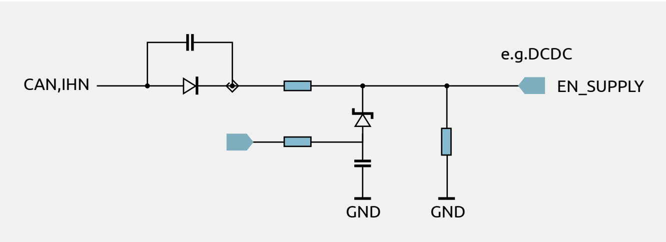
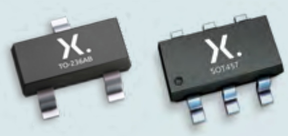


Fig. 15. Wake up circuit using small signal switching and Schottky diodes.

Discrete MOSFETs [28] and BJTs are now available in DFN packages[29, 30] offering significant board space saving 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.

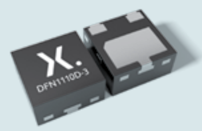
Suggested advanced Nexperia DFN packages



SOT23AB / SOT457
Occupied PCB area 11.4 mm^2

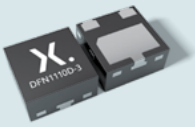
DFN2020MD-6
Occupied PCB area 5.1 mm^2
Space saving 55%

SOT323
Occupied PCB area 6.2 mm^2



DFN1110D-3
Occupied PCB area 2.5 mm^2
Space saving 60%

SOT23
Occupied PCB area 9.9 mm^2



DFN1110D-3
Occupied PCB area 2.5 mm^2
Space saving 75%

SOT363
Occupied PCB area 6.2 mm^2

DFN1412-6
Occupied PCB area 2.7 mm^2
Space saving 55%

Design challenge #7:

Controlling the power supply to parts of the design that don't need power all the time.
These parts can be radar antenna or communication interfaces.

Nexperia discrete solution to challenge #7

A load switch [3] serves to limit the power consumption of loads that are not used all the time. An additional role can be the protection of the loads from the damaging effects of short circuits and overvoltages by disconnecting the protected circuit [4]. 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.

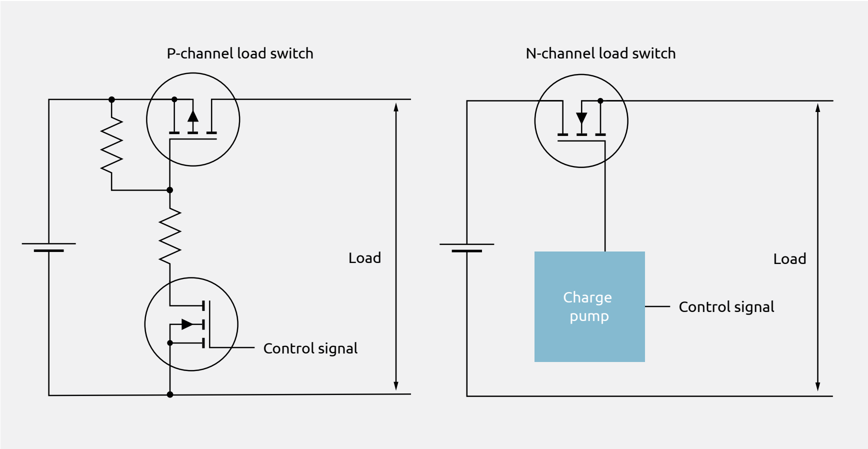


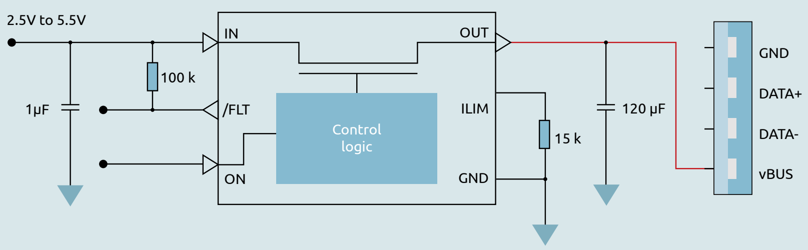
Fig. 16. Load switch realization with P-channel (left) and N-channel (right) MOSFETs.

Nexperia Integrated solution for challenge #7:

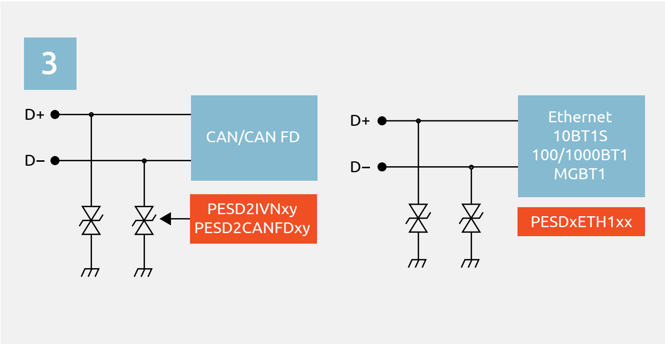
Integrated load switches can be used to activate the radar's antennae [13] like the NPS4053-Q100 [14]. Integrated load switches inherently require less design-in effort, smaller board space and fewer external components as well as integrated protection functions, albeit they are typically produced for lower current ratings than their discrete solution counterparts. They might be ideally suited for radar applications, due to the low power requirements and space constraints.

Suggested Nexperia integrated load switches: NPS4053-Q100

- Input voltage range: 2.5V to 5.5V
- 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
- 15kV ESD protection as per IEC 61000-4-2



5.3 Communication interface



Design challenge #8:

Protecting data lines from external voltage surges and bursts. Data lines have higher data rates than previously discussed power and signal lines.

CAN and Ethernet are typical in-vehicle networks used for interfacing the automotive radar, 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 test 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 28V 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 Application Note AN11882 [33] or Nexperia handbook on Automotive ESD protection [2].

A generic solution for realizing the protection for CAN is shown in the figure 17 [34].

Nexperia solution for challenge #8:

ESD devices serve predominantly to protect data lines [31, 32]. 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 Figure 18 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 [2].

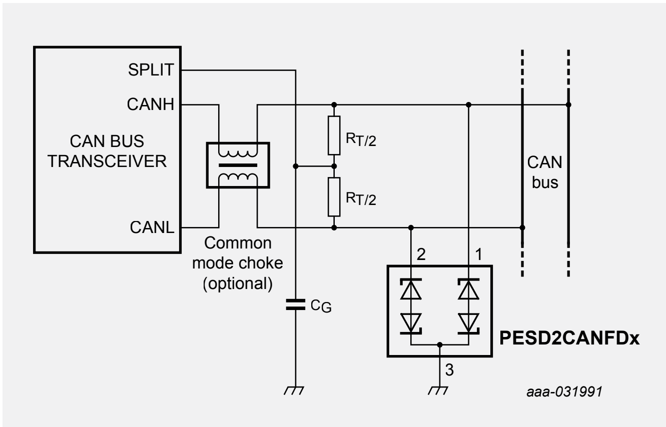


Fig. 17. Generic CAN interface.

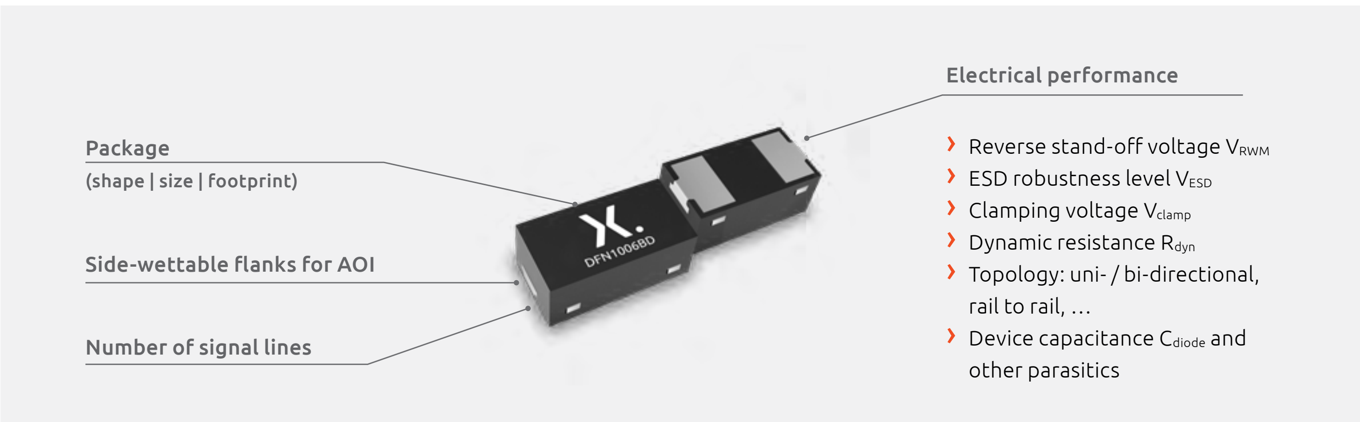


Fig. 18. ESD devices selection criteria.

Alternatively, Ethernet can be connected directly to the radars interface, in which case the below protection diagram can be used [36]. The OPEN Alliance proposes two possible external ESD protection devices [36]. As shown in the figure below, 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 [37]. 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.

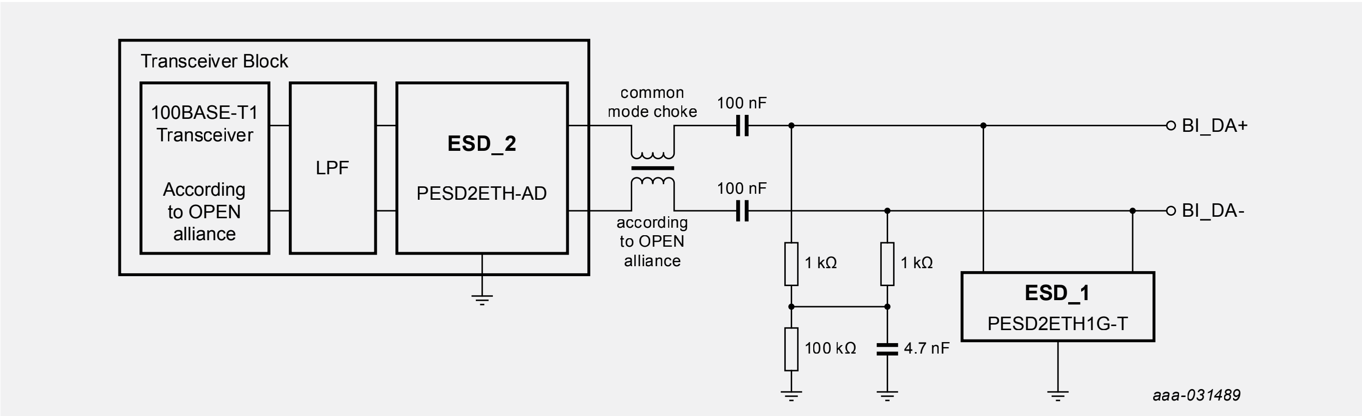
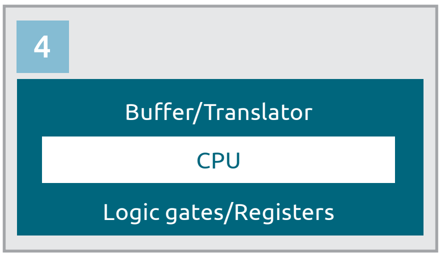


Fig. 19. Interface topology for 100BASE-T1 according to OPEN Alliance with placement of ESD protection at the connector and as part of the transceiver block.

5.4 Signal control



Design challenge #9:

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

Nexperia solution for challenge #9:

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 Figure 20 below for examples. Nexperia offers a wide portfolio of essential logic and signal chain devices. They are available in a variety of packages[38] and technologies to accommodate pin compatibility and compatibility with connecting block technologies. For complete information on Nexperia Logic devices, refer to the Logic handbook [39]. The next page summarizes some of the input and output features.

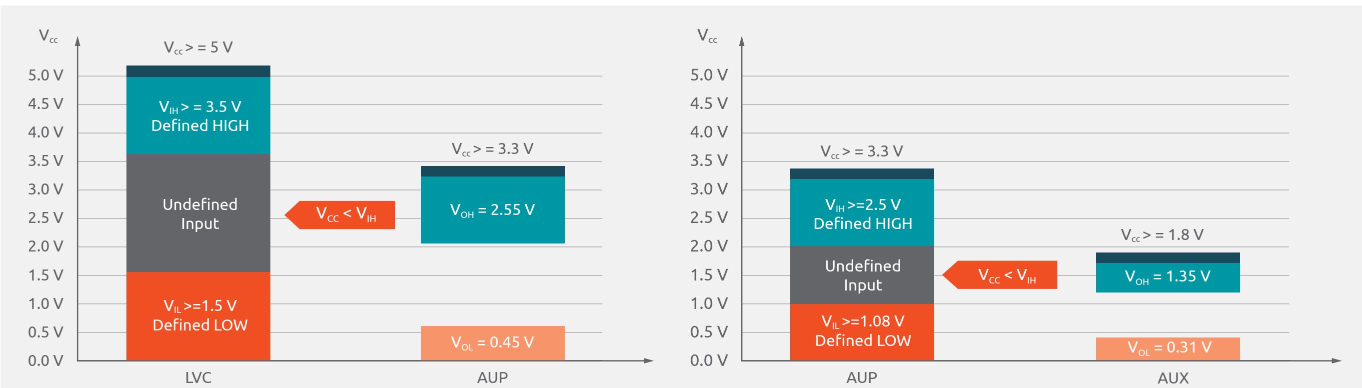


Fig. 20. Example of device families with incompatible voltage levels: LVC and AUP (left) and AUP and AUX (right).

Signal conditioning

For the signal chain, 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. 21)
- ESD protected to enable high to low voltage translations (Fig. 22)
- Low threshold inputs, can be used for low to high level translation
- Schmitt trigger inputs, to remove noise from signals (Fig. 23)

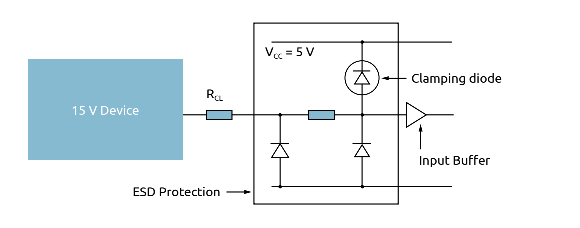


Fig. 21. Clamp diode protected input simplified schematic.

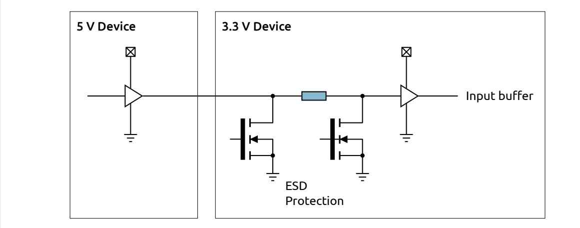


Fig. 22. ESD protected inputs simplified schematics.

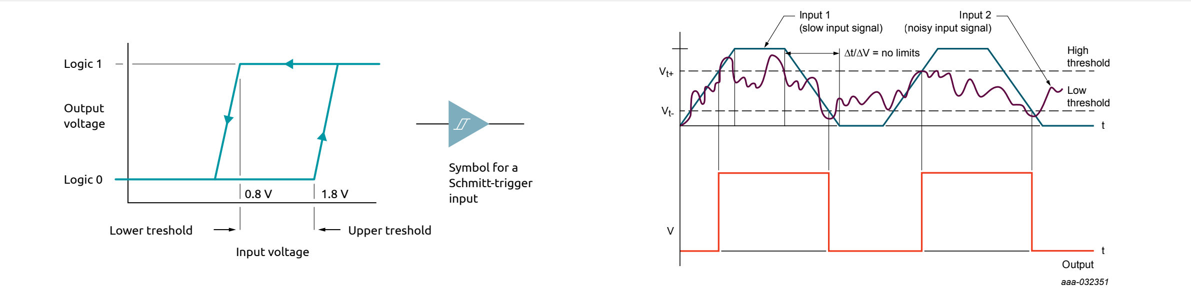


Fig. 23. Schmitt trigger inputs input hysteresis curve (left) and signal response (right).

While device outputs can be:

- Open drain outputs, enables Low to High and High to Low level translations (Fig. 24)
- 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. 25).

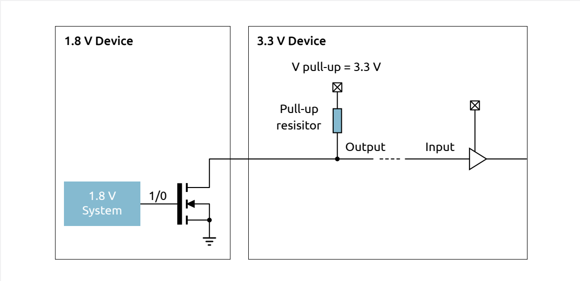


Fig. 24. Open drain outputs simplified schematic and example of utilisation.

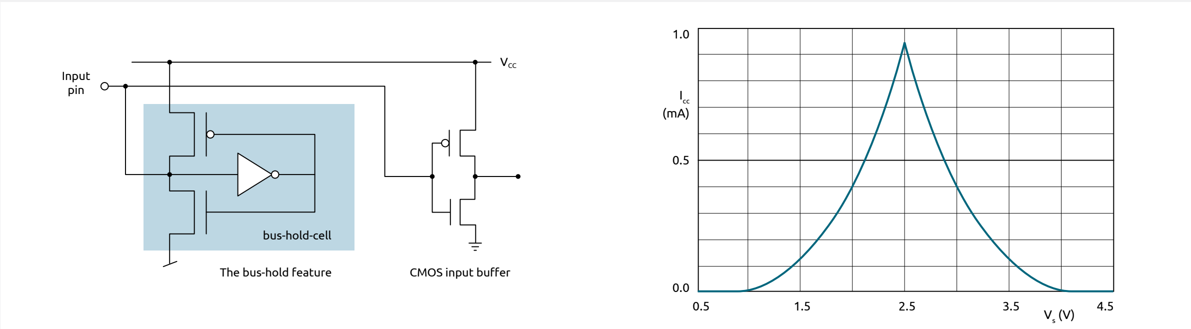


Fig. 25. Bus hold feedback functional schematic (left) and output current and voltage graph (right).

Buffers, trascievers and translators are used in radars 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 radar module. The two can sometimes operate on different supply voltages, which is where translators are handy.

Interface logic is also used to increase low-drive microcontroller outputs to drive high-load peripherals. 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.

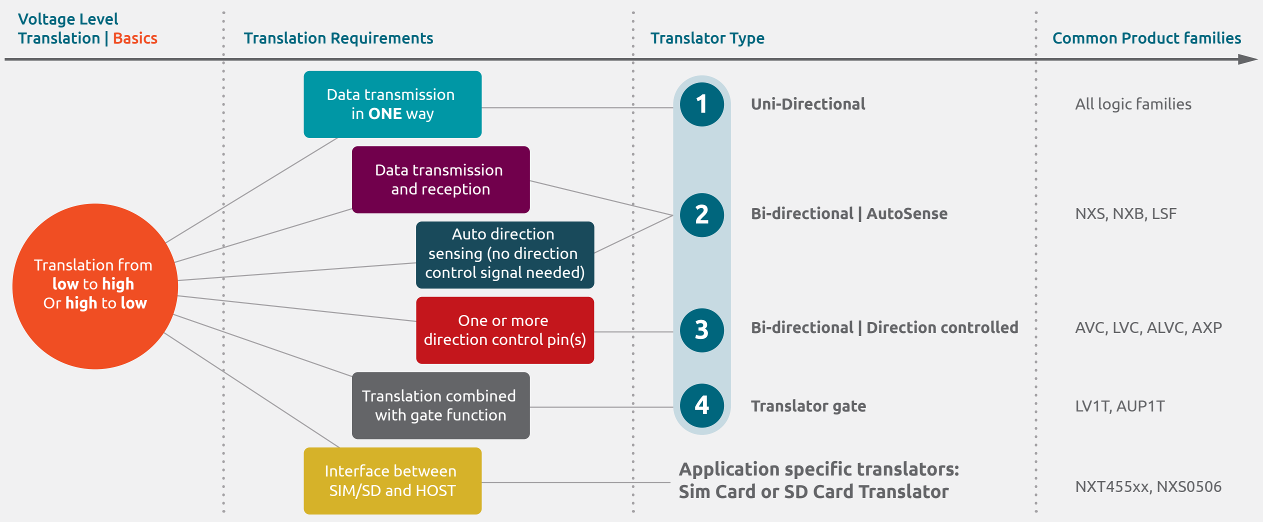
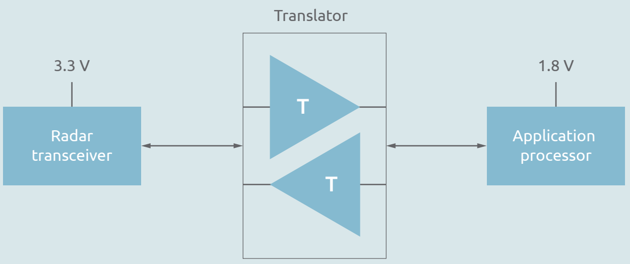


Fig. 26. Voltage translator selector tool.

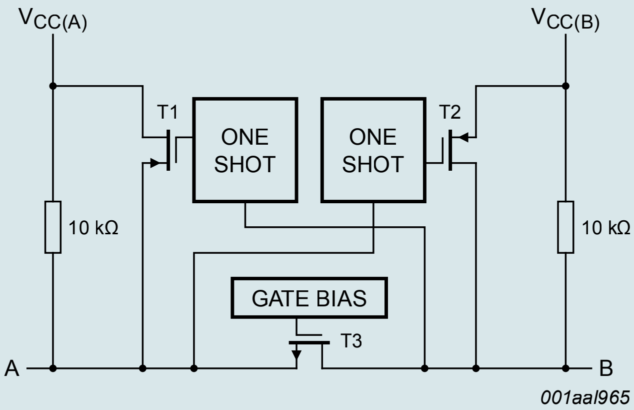
Suggested Nexperia Translator: LSF0101GW-Q100

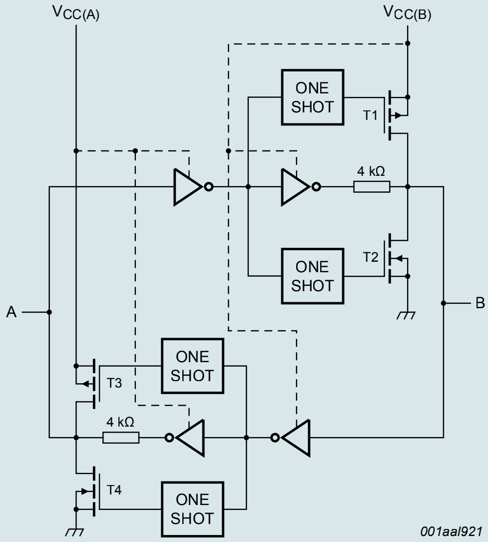


An interesting product to consider here is the LSF0101GW-Q100, a 1-Bit bi-directional translator with auto-direction sensing [40]. It has:

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

Suggested Nexperia Translators: NXS0101GW-Q100 and NXB0101GW-Q100





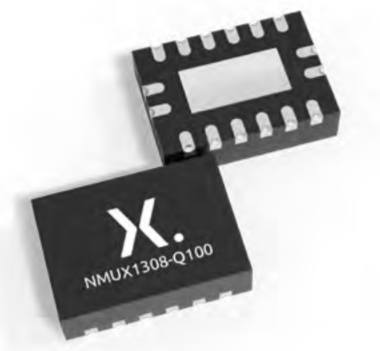
The NXS0101GW-Q100 and NXB0101GW-Q100 additionally provide acceleration of the signal rising edge and rising and falling edge, respectively. By driving the output stronger, these devices achieve faster data rates.

Other additional features include:

- Wide supply voltage range
- V_{CC} isolation
- Multiple package option

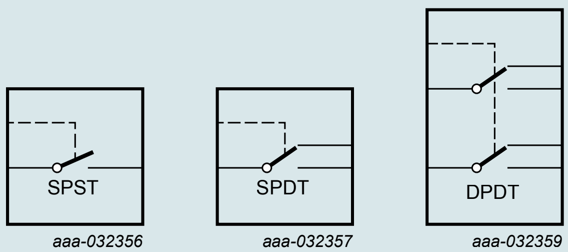
Design challenge #10:

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 #10:
Analog switches can be used in radar systems 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 2x SP4T-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
- 1.5V to 5.5V 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 #11:

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

Nexperia solution for challenge #11:

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. 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

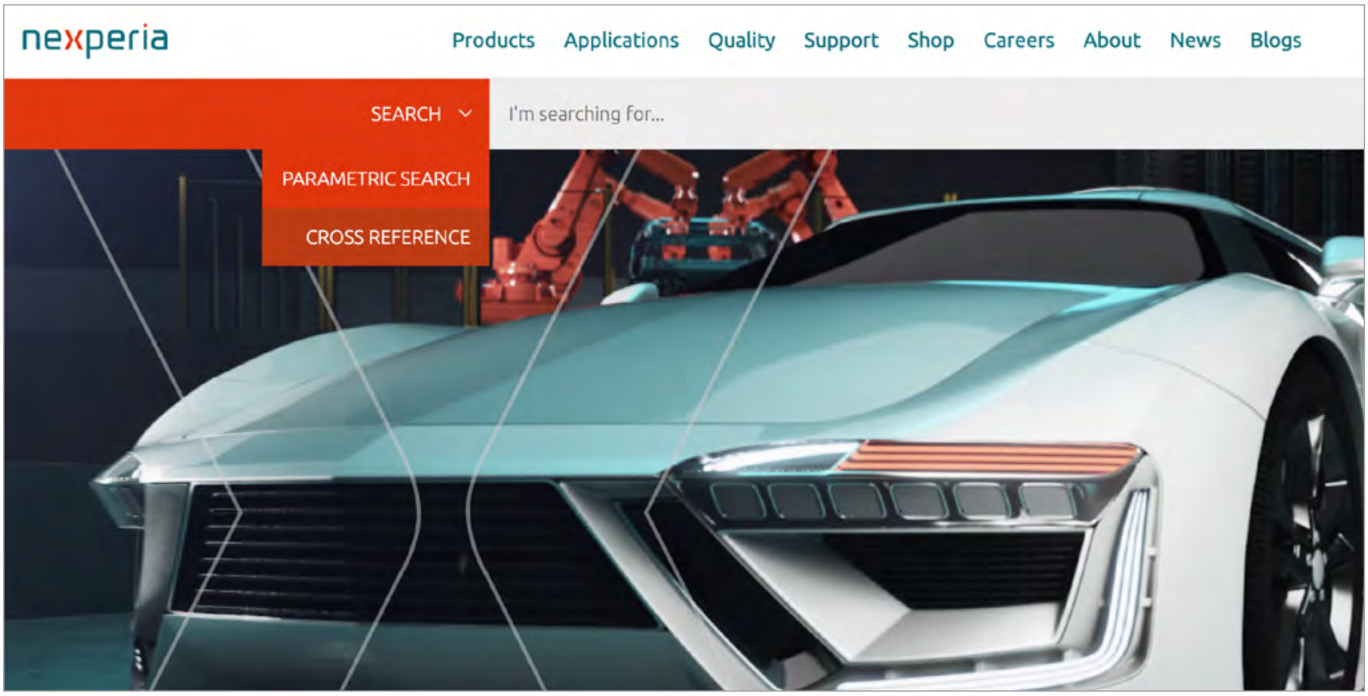
		HEF4000B	HC(T)	AHC(T)	VHC(T)	LV-A(T)	CBT(D)	LVC	LV1T	NXS(B)	LSF
Parameters	Supply voltage (V)	3.0 - 15.0	2.0 - 6.0	2.0 - 5.5	2.0 - 5.5	2.0 - 5.5	4.5 - 5.5	1.65 - 5.5	1.6 - 5.5	1.65 - 3.6 2.3 - 5.5	0.95 - 5.0
	Propagation Delay (TYP) (ns)	90	9	5	4	3.4	0.25	1.7	13.5	5.2	0.7
	Output drive (mA)	±3	±8	±8	±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

		LV	LVC	LVT	ALVC	CBTLV(D)	AUP	AVC	AXPnT	CB3Q	AUP1T	XS3A	NXT
Parameters	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					●						●	

6. Recommended products

Nexperia offers a wide portfolio of essential semiconductor devices. To find an equivalent to the used device please refer to the Nexperia website, cross reference search.



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, <185C 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, <185C Temperature stability	PTVS33VS1UTR-Q
Load switch and reverse battery protection		
PMOS	LFPAK56, 33 and DFN2020MD, 40-60V, P-channel devices	BUK6Y14-40P, BUK6Y24-40P
NMOS	LFPAK33, 40V, N-channel device, Rds(on) 3-15mOhm, Logic Level gate treshold	BUK9M3R3-40H, BUK9M4R3-40H
		BUK9M7R2-40E, BUK9M9R1-40E, BUK9M11-40E, BUK9M14-40E
	LFPAK33, 40V, N-channel device, Rds(on) 3-15mOhm, Standard Level gate treshold	BUK7M3R3-40H, BUK7M4R3-40H, BUK7M15-40H
		BUK7M6R3-40E, BUK7M8R0-40E, BUK7M10-40E, BUK7M12-40E
	LFPAK56D, 40V, Dual N-channel device, Rds(on) 3-30mOhm, Logic Level gate treshold	BUK9K13-40H
		BUK9K6R2-40E, BUK9K6R8-40E, BUK9K8R7-40E
	LFPAK56D, 40V, Dual N-channel device, Rds(on) 3-30mOhm, Standard Level gate treshold	BUK7K6R2-40E, BUK7K6R8-40E, BUK7K8R7-40E
	DFN2020MD-6, 40V, N-channel device, Rds(on) 10-30mOhm	BUK9D23-40E, BUK6D23-40E, BUK7D25-40E, BUK6D30-40E
	MLPAK33, 40V, N-channel devices, 4.6-7.5mOhm, Logic Level gate treshold	BXK9Q4R6-40H, BXK9Q7R0-40H
	MLPAK33, 40V, N-channel devices, 4.6-7.5mOhm, Standard Level gate treshold	BXK7Q4R9-40H, BKX7Q6R0-40H, BXK7Q7R5-40H
	SOT457, 40V, N-channel device	PMN20ENA, PMN30ENEA

Power electronics

Product	Description	Key part numbers
Load switch and reverse battery protection		
Schottky Diodes	40V, medium power, low VF Schottky barrier rectifier	PMEG4050EP-Q, PMEG4030ETP-Q
	30V, medium power, low VF Schottky barrier rectifier	PMEG3050EP-Q, PMEG3030BEP-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
Gating circuitry		
ssMOSFET	SOT23/SOT363/SOT323, 30V, N-channel device, Rds(on) 1Ohm, 2kV ESD protection	NX3008NBK
	SOT23/SOT363/SOT323, 60V, N-channel device, Rds(on) 1Ohm, 1,5kV ESD protection	BSS138BK
	SOT23/SOT363/SOT323, 60V, N-channel device, Rds(on) 1Ohm, 2kV ESD protection	2N7002BK
Power management 2		
NMOS	LFPAK33, 40V, N-channel device, Rds(on) 10-20mOhm, Logic Level gate threshold	BUK9M11-40H, BUK9M15-40H, BUK9M20-40H
	LFPAK33, 40V, N-channel device, Rds(on) 10-20mOhm, Standard Level gate threshold	BUK7M11-40H, BUK7M15-40H, BUK7M20-40H
	LFPAK56D, 40V, Half Bridge N-channel device, Rds(on) 4.2mOhm and 13mOhm	BUK9V13-40H, BUK7V4R2-40H
	LFPAK56D, 40V, Dual N-channel device, Rds(on) 10-20mOhm, Logic Level gate threshold	BUK9K13-40H
	SOT457, 40V, N-channel device, Rds(on) 19mOhm and 23mOhm	PMN20ENA, PMN30ENEA
	MLPAK33, 60V, N-channel devices, 29mOhm	BXK9Q29-60E
	LFPAK56D, 100V, Dual N-channel switching device, Rds(on) 10-30mOhm	BUK9K14-100L
	LFPAK56D, 80V, Dual N-channel switching device, Rds(on) 10-30mOhm	BUK9K14-80L
	LFPAK33, 100V, N-channel switching device, Rds(on) 10-30mOhm	BUK9M13-100L
	LFPAK33, 80V, N-channel switching device, Rds(on) 10-30mOhm	BUK9M11-80L, BUK9M20-80L, BUK9M35-80L
	MLPAK33, 40V, N-channel devices, 4.6-7.5mOhm	BXK9Q4R6-40H, BXK9Q7R0-40H, BXK7Q4R9-40H, BXK7Q7R5-40H
	DFN2020MD-6, 40V, N-channel device, Rds(on) 20-30mOhm	BUK6D23-40E, BUK9D23-40E, BUK7D25-40E, BUK6D30-40E
Schottky Diodes	CFP3, 40 V low VF Trench Schottky barrier rectifier	PMEG40T10ER-Q, PMEG40T20ER-Q, PMEG40T30ER-Q
	CFP3, 60 V low leakage current Trench Schottky barrier rectifier	PMEG60T10ELR-Q, PMEG60T20ELR-Q, PMEG60T30ELR-Q
	CFP3, 100 V low leakage current Trench Schottky barrier rectifier	PMEG100T10ELR-Q, PMEG100T20ELR-Q, PMEG100T30ELR-Q
Step down (Buck) converter	SOT23-6, 4.5-40V Vin, 600mA Synchronous Buck converter	NEX40400-Q100
	QFN-12, 3.8-40V Vin, 2A/3A Synchronous Buck converter	NEX40402/3-Q100
	QFN-8, 6-100V Vin, 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
uC core power supply		
ssMOSFET	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
BJTs	SOT23 superior power dissipation bipolar transisto	BC817K-16, BC817K-25, BC817K-40
	DFN2020-3 power bipolar transistors	BC54PA-Q, BC54-10PA-Q, BC54-16PA-Q
	DFN1006(B)-3, 250mW, 15V and 40V low Vcesat bipolar transistors	PBSS2515MB, PBSS2540M, PBSS2540MB
	SOT323, 250mW, 40V and 60V low Vcesat bipolar transistors	PBSS4140U, PBSS4160U
	DFN1010, 325mW, 30V and 60V low Vcesat bipolar transistors	PBSS4260QA
	SOT23, 300mW, 20V, 30V, 40V, 50V and 60V low Vcesat bipolar transistors	PBSS4160T-Q
	SOT457, 360mW, 20V, 40V, 50V and 100V low Vcesat bipolar transistors	PBSS8110D
Shunt regulators	SOT23, 3-terminal adjustable shunt regulators	TL431BQDBZR-Q
Power distribution		
High side switch	40V, 200mΩ Smart High Side switch	NPS6210
LDO	40V/300mA LDO with 5uA ultra low Iq in HVSSOP-8 and SOIC-8 package	NEX90530BPA-Q100
	40V/150mA LDO with 5uA ultra low Iq in HVSSOP-8, SOT23-5, SOT223-4 and DFN-6 package	NEX90515BPA-Q100

Signal electronics

Product	Description	Key part numbers
Communication interface 3		
ESD for CAN and IVN	SOT23, <17pF, 30kV protection for 12V board net	PESD2IVN27T-Q
	SOT323, <17pF, 30kV protection for 12V board net	PESD2IVN27U-Q
	SOT23, 3.2-10pF, 30kV protection for 12V board net	PESD2CANFD24UT-Q
	SOT323, 3.2-10pF, 30kV protection for 12V board net	PESD2CANFD24UU-Q
	DFN1110D-3, 3.5-10pF, 30kV protection for 12V and 24V board net	PESD2CANFD24UQB-Q
	DFN1412D-3, 3.5-10pF, 30kV protection for 12V and 24V board net	PESD2CANFD24UQC-Q
	SOT23, 3.9-10pF, 30kV protection for 24V board net	PESD2CANFD36UT-Q
	SOT323, 4.3-10pF, 30kV protection for 24V board net	PESD2CANFD36UU-Q
	SOT23, 8pF, 30kV protection for 48V board net	PESD2IVN48T-Q
ESD for Ethernet (ESD_1 from Fig. 19)	SOT23, 1-3pF, 30kV protection, 24V standoff voltage	PESD2ETH1GXT-Q
	DFN1006BD-2, 1.2-1.8pF, 30kV protection, 24V standoff voltage	PESD1ETH1GXLS-Q
ESD close to PHY (ESD_2 from Fig. 19)	DFN1006-2, 0.35pF, 10kV protection, 18V standoff voltage	PESD18VF1BBL-Q
	DFN1006-2, 0.3pF, 10kV protection, 24V standoff voltage	PESD24VF1BBL-Q
	DFN1006-2, 0.4pF, 12kV protection, 30V standoff voltage	PESD30VF1BBL-Q
	DFN1006BD-2, <0.6pF, 10kV protection, 5V standoff voltage	PESD5V0C1BLS-Q
Signal control 4		
Inverters/Buffers/ Transceivers/Logic gates/ Registers	AHC(T) product family, Vcc 2-6V (4.5-5.5V)	74AHC08BQ-Q100
	HC(T) product family, Vcc 2-6V (4.5-5.5V)	74HC2G08DC-Q100
	LVC product family, Vcc 1.2-3.6V	74LVC126ABQ-Q100
	AUP product family, Vcc 0.8-3.6V	74AUP2G80DC-Q100
Translators	AVC product family, Vcc 0.8-3.6V	74AVC1T45GW-Q100
	HC(T) product family, Vcc 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

References

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2 ESD_Application_Handbook_Automotive_Edition
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22 BJT_Handbook_V2
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