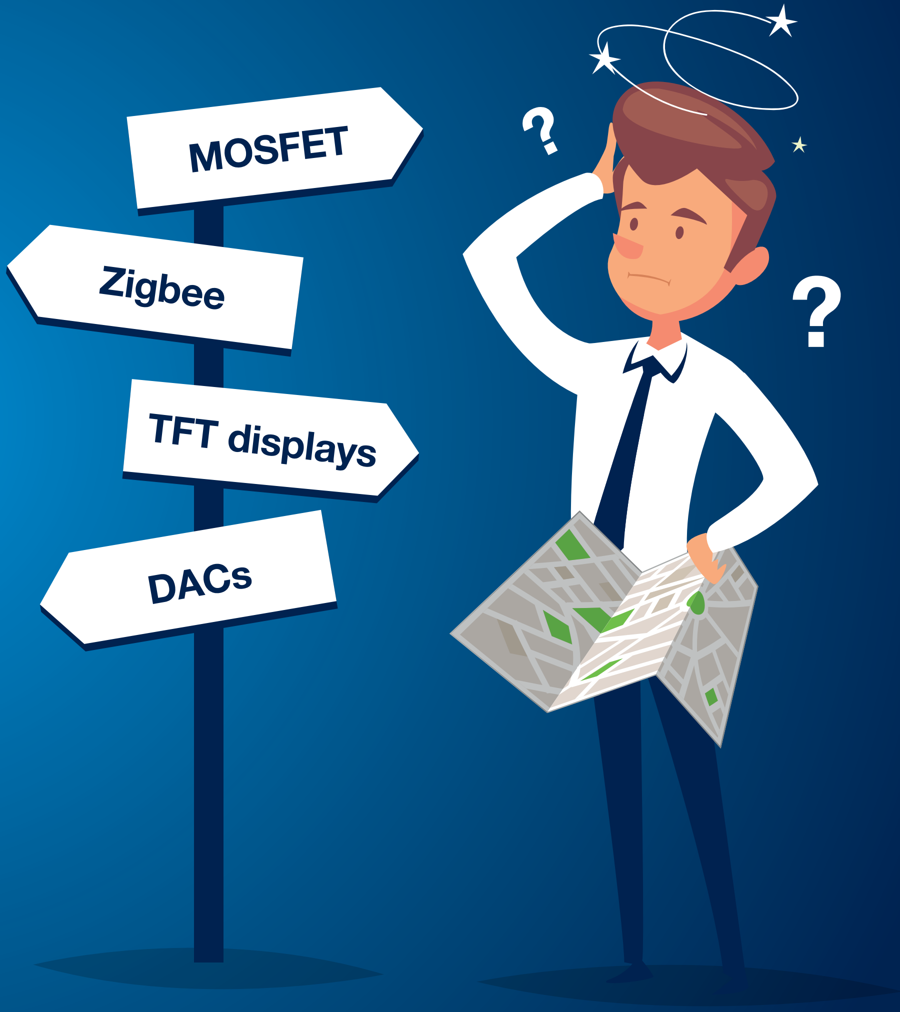
Understanding the Basics: **A Technology Guide for Component Buyers**



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Foreword

The sourcing of electronics components is a complicated process. Modern designs are becoming increasingly complex as the technology they utilise advances. For the engineer, product selection can involve significant research: checking datasheet specifications, investigating second-source options, determining fit into available board space. However, when it comes to procuring the components, it's easy to overlook the equally daunting set of commercial and logistical challenges faced by the purchasing team!

If procurement and purchasing professionals are equipped with basic technical knowledge, they can fully understand the context of the selection decisions, and use this insight to support meaningful and productive dialogue with their engineering colleagues.

It was this goal that prompted Mouser Electronics, as part of its ongoing drive to strengthen the engagement between purchasing and engineering teams, to create this 'Understanding the Basics' guide.

The guide provides a comprehensive resource that purchasing staff can refer to when they need more information on a particular technology area, or what relevant alternatives exist. It also offers valuable advice on other pressing supply chain challenges such as end-of-life (EoL), component traceability, conflict minerals, e-waste, counterfeit products, effective use of sourcing tools, better inventory management, and automated order processing.

Mouser would like to get your input on this too – so if you have ideas about what further subjects should be covered, then contact us at **buyersguide@mouser.com**.

Contents

Wireless Technology

Wireless communication is omnipresent today. It connects devices so they can transfer data and interact. There are several wireless communication methods, also termed protocols, in use. Each has slightly different characteristics in terms of speed of data transfer, physical range of communication and the amount of power required. Each method typically best suits specific applications and use cases.

In this chapter, we highlight some of the popular wireless protocols currently in use, and also investigate some emerging wireless protocols entering the market.

Wireless Networking

If asked to name a wireless technology, most people would probably say Wi-Fi. Some might answer cellular communication, which is equally pervasive. Wi-Fi is available in most places, and we have all become adept at finding it in public spaces such as shopping malls, airports and coffee shops. In a relatively short period, it has become as desirable as the utility of mains (line) power. Wi-Fi continues to extend its reach, finding new applications in our cars (vehicles), on public transport (transit), and in concert venues.

Wi-Fi creates a wireless local area network (WLAN) that is used by devices such as personal computers, printers, games consoles, smartphones, smart TVs and all manner of Internet-enabled household appliances. All these devices create an individual connection to an access point, a router, in the case of our home setup. Through the router they can connect, for example, your smart speaker playing music from a network-attached hard disk. The router usually links the network back to the Internet (as shown in Figure 1). Wi-Fi can also be used to create an 'ad hoc' network where devices talk directly to each other instead of via an access point.

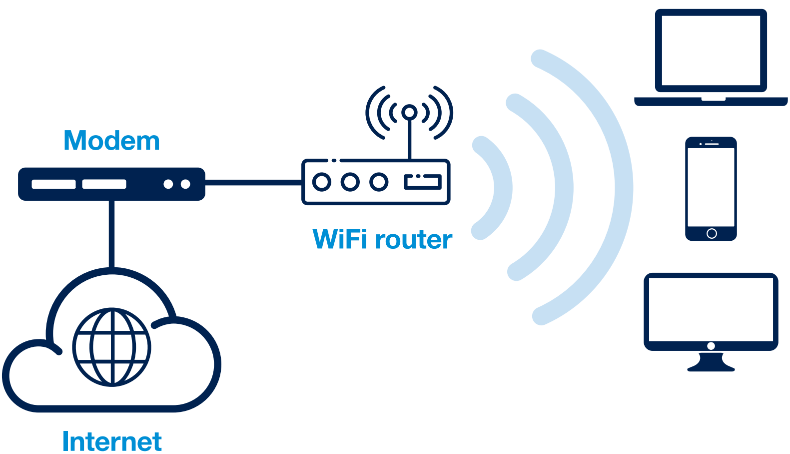


Figure 1: A typical Wi-Fi network

Since its inception in the early 1990s, there have been many enhancements to the Wi-Fi specification resulting in faster data rates, increased range and higher levels of security. The IEEE standard 802.11 defines the hardware and communication protocols used by Wi-Fi. The Wi-Fi Alliance, a trade association, defines certification procedures and interoperability testing. For a new product to display the Wi-Fi logo, it needs to be validated against and comply with the Wi-Fi Alliance test specifications.

Wi-Fi uses two different frequency bands, 2.4 GHz and 5 GHz, and has a maximum range of about 10 m to 30 m indoors. Dense building materials such as thick stone walls and concrete floors can absorb much of the Wi-Fi signal, significantly limiting the range. Also, baby monitors and Bluetooth-enabled devices use the same 2.4 GHz frequency band, creating the possibility of interference.

Each version of Wi-Fi is denoted by the addition of a suffix letter, with 802.11b being the first version of Wi-Fi that was widely adopted. The standard is backward compatible such that new devices can support all the previous standards as well as the latest.

The current standards are:

- 802.11b – the basic 2.4 GHz standard.
- 802.11a – the first 5 GHz standard, which provided higher speed but a more limited range.
- 802.11g – a faster version of 802.11b, which is up to three times faster due to the way data is encoded.
- 802.11n – which uses multiple antennas at 2.4 GHz and 5 GHz to do 'beamforming' that directs the signal at a target device, providing increased speed and range (up to 70 m indoors).
- 802.11ac – which allows more antennas with new encoding schemes to deliver much higher data rates at 5 GHz.

Designers of consumer devices and embedded systems that need to support Wi-Fi communication can buy ready-made Wi-Fi modules that include all necessary wireless functions, including antennas and a microcontroller, with software to manage the communication. These modules are certified by the manufacturers, making it a relatively quick and easy task to add Wi-Fi to an existing product.

Wireless for Personal Networks

Another prevalent wireless communication protocol is Bluetooth. Designed to replace the wired connections between nearby devices, Bluetooth creates a wireless personal area network (WPAN). It uses the same 2.4 GHz frequency band as Wi-Fi but works over much shorter distances and at lower data rates to reduce power consumption. As there are some associated security weaknesses, it is often recommended to only turn on Bluetooth when it is required.

Some typical applications for Bluetooth include:

- Connecting a phone and wireless headset – this was one of the first use cases and helped drive initial Bluetooth sales.
- Linking a phone and car audio system to allow hands-free calls and playing music.
- Playing music through wireless speakers.
- Pairing wireless fitness trackers or watches to a mobile phone or computer.
- Using a wireless keyboard or mouse with a computer.
- Transferring files between devices.

New applications, such as wearable electronics, e-medicine and the Internet of Things (IoT) are set to drive future demand. In 2016, annual Bluetooth IC shipments were around 1.6 billion units, and this rose to just over 3 billion last year. Market analyst firm ABI Research predicts this may rise to 5 billion by 2021. The Bluetooth Special Interest Group (SIG) controls the Bluetooth standard. The Bluetooth SIG manages the development of the standard and qualification program. It also owns the trademarks, so the name and logo are subject to licence and compliance. Interestingly, the Bluetooth name came from a 10th-century Danish king, Harald Bluetooth, who united the tribes of Denmark into a single kingdom. The logo is made up of letters, or runes, that are used for the king's initials.

Low-Power Networking for Control

Zigbee and Z-Wave are two very low-power wireless communication protocols that are intended mainly for applications such as home automation, where sensors and control devices are typically powered using a small coin cell and need to have a lifetime of years.

Both wireless protocols are designed to be low-cost and require a minimal power budget. Because of this, they are capable of relatively low-bandwidth and short-range (tens of metres, line-of-sight) communications links. They are suitable for low-data-rate applications with intermittent data transmission such as intruder or smoke alarms, industrial controls, light switches, thermostats, and similar sensors and controls.

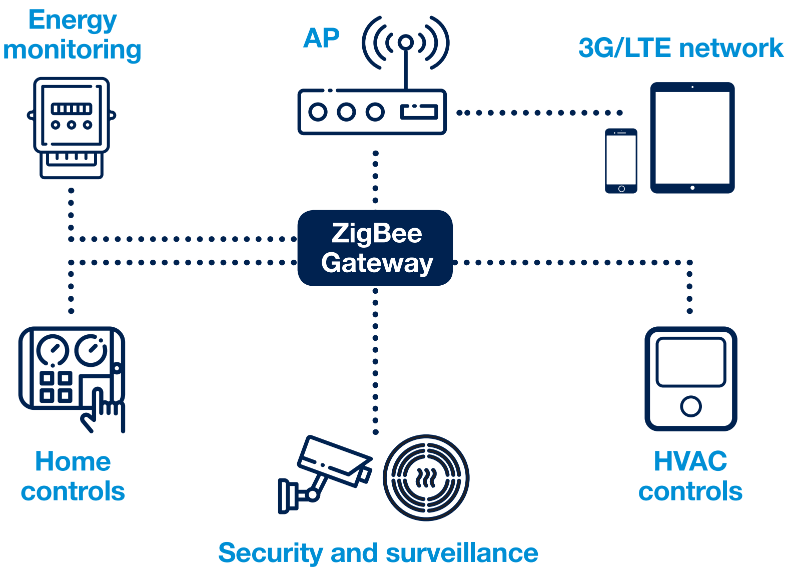


Figure 2: Use of wireless in home automation systems

The Zigbee specification is an open standard defined by an industry group, the Zigbee Alliance. All designs need to pass its validation tests. In contrast, Z-Wave is a proprietary communications protocol using IP licensed by Silicon Labs. It has a slightly lower bandwidth but a more extended range than Zigbee. As it is more straightforward to develop with, it may be easier to design a system using Z-Wave; however, this also means it is not as flexible as Zigbee.

Contactless Identification

Radio frequency identification (RFID) and near-field communication (NFC) are two similar wireless technologies widely adopted for product tracking, access control systems and other contactless applications.

RFID tags are widely used for stock control and logistics applications, allowing the position and movement of items to be monitored through a production line or warehouse, to help prevent theft. We experience the need for the tag to be removed or neutralised by a scanner when buying goods in a shop. Access control cards, e-passports and payment systems also use RFID technology.

RFID uses electromagnetic induction between loop antennas in the tag and a reader. Tags are data stores that can be accessed by the reader. There are two types of tag:

- Active tags – which have a battery to generate the radio signal, allowing more extended range, but increased cost and limited lifetime.
- Passive tags – which use the energy in the signal picked up by the tag's antenna to power the device, thereby limiting the range of operation, but making the tags much cheaper.

There are a variety of different RFID standards created by industry organisations and national bodies, as well as numerous proprietary systems. Furthermore, countries do not all use the same radio frequencies – so a European tag might not work in the USA, for example. There is limited security designed into RFID tags, and there are privacy concerns about the ability to track people who are carrying or wearing tagged products.

The International Organization for Standardization (ISO) manages the NFC specification, in addition to promotion by various industry bodies, including the NFC Forum. It extends the technology behind RFID to allow more flexible communication between devices. A device can act as both a tag and a reader, thus enabling two-way, peer-to-peer communication. NFC includes better security than RFID, making it more suitable for contactless payment and access control functions. NFC capabilities are incorporated into almost all smartphone models, which enables contactless payment and the exchange of information between handsets.

High-Speed Wireless Communications Replace Cables

There are several new and emerging wireless standards aimed at replacing the cables that connect video and audio devices, such as DVD players and TVs. Examples are WiGig and WirelessHD. These systems use much higher frequencies than Wi-Fi to provide much faster data rates. However, at 60 GHz, the signals do not pass through walls, limiting communication to line-of-sight operation between devices, with a range of about 10 m. WiGig can transfer 1,000 photos between computers in 5 seconds. Uploading a 2-minute HD video recording from a camcorder would take about 1 minute over a Wi-Fi connection, but a mere 3 seconds over WiGig. The Wi-Fi Alliance manages the WiGig standard, but it was given a new name to highlight the fact that it is not backward compatible. It is intended to complement Wi-Fi rather than replace it. WirelessHD is a proprietary protocol targeting the same applications and with similar performance and range characteristics.

There are many other wireless communications methods in use, and more being developed. Only time can say which of these will become as ubiquitous as Wi-Fi or Bluetooth. One of the challenges that procurement staff face is the uncertainty about which emerging standards become established and popular. Though engineers may look to gain a performance advantage through selecting a specific protocol and ICs for their design, the choice might not bring success if the chosen technology fails to gain widespread deployment.

Connectors and Cabling

Interconnection is an essential element of every electronic system. Typically used to provide internal connectivity between PCBs and sub-systems, and as an interface to the outside world, connectors and cables transfer power, analogue signals and digital data. There are many different types of connectors available, based on industry standards and specific application requirements. As new applications, technologies and commercial pressures create the need for new types of connectors, suppliers come up with innovative designs and interconnection methods. This chapter of our purchasing guide looks at some of the most popular connector types, and gives advice and guidance on selecting a specific connector solution.

PCB Connectors

This category includes board-to-board and board-to-cable connector components. These connectors are almost exclusively used inside a system and provide internal layout flexibility. Connectors also permit the separation of specific circuit functions, enabling a modular design approach. Using connectors to connect sub-systems and discrete functions further eases working on a system during manufacture, for testing and compliance, and throughout its service life.

PCB connectors range from very low-cost pin-and-socket solutions to very high-density, low-profile solutions with high-performance requirements used in space-constrained environments. Some connectors used in applications that are susceptible to shock and vibration include the ability to attach the connector to the PCB mechanically. Others provide a latching or a de-mating function, while many use a compression fit between plug and socket to maintain the connection.

Specialist connectors are available for use with radio-frequency, high-voltage and high-current circuits. An example of new connector development is for use with mmWave high-frequency RF applications, particularly 5G. The slightest mechanical deflection of the PCB caused by the connector creates RF reflections, which lower communications efficiency. Likewise, for connectors used to convey power, careful attention should be paid to the size of the conductors. Too small a conductor might cause the connector to experience an unacceptable and potentially dangerous temperature rise during operation.

The materials used in the connector's construction should be carefully considered. The plastic insulator must be compatible with any soldering process and cleaning fluids used during production, as well as providing sufficient electrical insulation for any high-voltage signals during operation. The plating on the connector pins is often pure tin, to comply with RoHS requirements. Tin plating is perfectly acceptable for most use cases where the connectors are mated infrequently, but if the connector is cycled frequently, the addition of plating must be considered.

Wire-to-board connectors are similar to board-to-board connectors, except that the mating (usually female) part allows the attachment of cables, providing a connection to other parts of the system, including front panels or another PCB. One hidden cost here can be that of the tooling required to crimp the wires into the connector housing.

Fibre-Optic Connectors

With increasing data rates and a need for enhanced data security, the use of fibre-optic connectors is becoming increasingly popular. Available connector types include single-mode, multi-mode, small form factor (SFF) and several application-specific types, such as those used in audio/video equipment.

Signal attenuation or loss is a significant consideration for fibre-optic connectors – both the insertion loss as well as any return loss due to reflections. Many fibre-optic connectors include a spring mechanism to ensure that the mating faces (either glass-to-glass or plastic-to-plastic) are pressed together properly, thereby maintaining signal integrity.

Fibre-optic connectors are often used outdoors and may be located underground or exposed to the elements. If it is not possible to source a suitable sealed connector, customised protective enclosures are necessary. These will, of course, add cost and complexity to the assembly process.

Military-Grade Connectors

Reliability of connection is, without question, of paramount concern for many mission-critical military applications. In general, the size and shape of military connectors, as well as sealing requirements, reliability and performance, are all defined by a series of internationally recognised standards. Commercial off-the-shelf equivalents of military-grade connectors are finding use in many industrial automation systems, as reliability is key to maintaining overall operating efficiency.

Connector standards stipulate the outer housing design, locking mechanism operation and sealing methods, and compliance with the specification is crucial in maintaining connection reliability. Connection size and weight also need to be considered, as specific high-reliability applications are impacted by these attributes, especially for avionics or portable equipment.

While environmental factors dictate the mechanical facets of a connector, there is more flexibility in the type and nature of contacts used within the housing. Specialist military connector suppliers can populate a wide array of different contacts within a standard shell to support various application requirements. Common examples of contact types include signal, power, fibre-optic, USB and RJ45, but others are also possible.

Cabling

There are many types of cable available, and they all share one thing in common – they are designed to conduct power and electrical signals. Some cables may have a single conductor, but most have multiple conductors. A conductor may be a single solid copper wire or composed of multiple tinned wire strands, with the latter providing a high degree of flexibility. Not all conductors in a cable are necessarily the same in terms of size, shielding and current handling, with many having provision for power, analogue and digital signals.

As applications require higher data transfer speeds, the cable requirements become more sophisticated. RF cables are usually coaxial, meaning that the conductor is surrounded by a braided earth screen that shields the signal from interference and maintains load impedance. In data cabling, pairs of wires are often twisted together (referred to as a ‘twisted pair’) to preserve signal integrity and avoid cross-talk from other pairs in a cable. An Ethernet cable, for example, uses four sets of twisted pairs.

The size of individual conductors is defined by the signals they carry, and the length of the overall cable. In power cables, the ability to convey power without significant voltage drops or temperature rises is essential. In data cables, the acceptable level of signal attenuation is crucial in determining conductor dimensions and the maximum length.

The physical properties of the cable are also important. The outer jacket may be required to provide physical protection in harsh environments such as extremes of temperature and humidity, or may be rated to resist exposure to certain chemicals. Some cables are attached to moving parts, especially in robotics, so the ability to withstand constant flexing is vital.

Supplier Selection

Purchasing electromechanical devices such as connectors is no different than purchasing other electronic components, so buyers are recommended to follow industry best practices. However, there are a few considerations specific to purchasing interconnect products that might help guide the process.

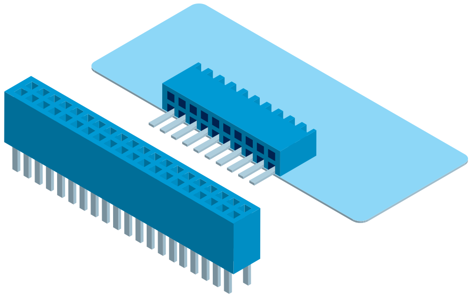
The construction of connectors and cables involves many different materials, including base metals, plating materials, surface finishes, insulators, cable sheathing, etc. Finding a supplier that makes information on all of these materials readily available can facilitate the process of complying with RoHS, REACH and conflict minerals legislation.

Reliability is key, as many connectors experience harsh environments and user abuse. Detailed manufacturer test data for the specific connector is invaluable, especially for connectors that are frequently mated/unmated, ensuring that the chosen connector does not compromise system reliability. As engineers are challenged to fit connectors into small spaces without impeding airflow, as well as providing adequate access for assembly and repair operations, the availability of 3D models for the connector can save design time and mitigate costly mistakes.

Key Connector Types

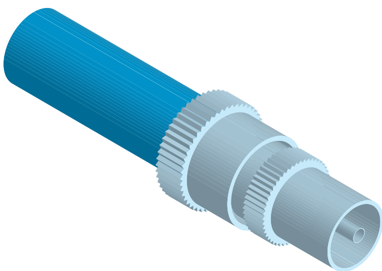
Board-to-Board:

Also called PCB connectors or headers, these are used to connect PCBs and sub-systems, or to terminate wires to PCBs from external connectors or front panel controls. There are a wide variety of mounting options and connection features available, such as multiple pins, latched and keyed. There are also screw-in, crimp and solder types. The pitch of the pins is another attribute, with 0.1-inch pitch spacing widely used. Selecting lower-cost plastics or plating can impact reliability. They may require mechanical supports, and crimping tools can represent an additional cost.



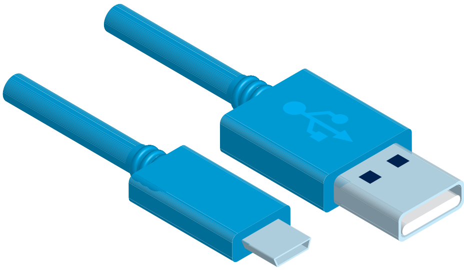
Coaxial:

These suit use in radio frequency (RF) applications – including TVs, cellular and instrumentation. The conductor is surrounded by a shield to prevent noise affecting signal integrity, and most types include a latch mechanism. Cable impedance and operating frequency are vital selection criteria. Size varies according to the operating frequency range and, if used for high-RF power distribution, the power/voltage rating. Popular types are BNC, SMA, SMB and 'N' type.



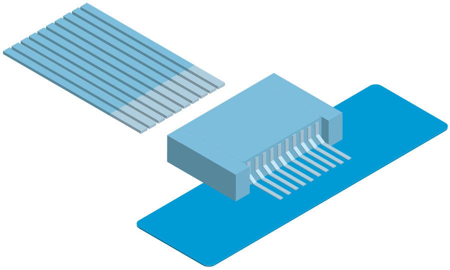
USB:

Defined by the universal serial bus (USB) standard, these are now commonplace in portable electronics-based equipment and computer peripherals – enabling data and power transfer. Early versions of the standard require a different plug/socket for the host/peripheral and are available in different sizes (standard, mini and micro). USB Type-C standardises the connector for mating either way around. USB-A and USB Micro-B connectors are still in widespread use. Innovations in data transfer rates and power delivery through USB continue to advance.



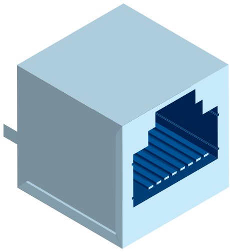
FFC/FPC:

These are flexible flat cable (FFC) and flexible printed circuit (FPC). This high-density latching connector system comprises separate connectors and flat cables for connecting PCBs. Fine-pitch versions (0.2 mm) are available for compact spaces, and connectors can have up to 260 contacts. There are a wide range of options – including plating, contact orientation, termination and cable length.



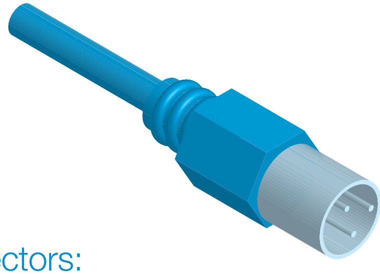
Modular Jacks:

Primarily designed for telephone and data connections such as Ethernet, these are specified by the number of positions and number of contacts fitted. All plugs have a latching mechanism, and some sockets include indicator LEDs to show port data activity and connection data rate. RJ11, RJ14, RJ25 and RJ45 types are widely adopted.



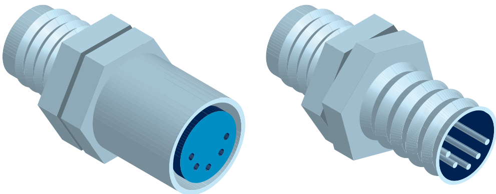
Audio:

This describes a wide variety of mostly circular connectors meeting standards such as RCA phono, jack (2.5 mm, 3.5 mm, 6.35 mm), XLR and DIN. With their wide availability, this connector format finds use in proprietary applications other than audio. They are subject to frequent and rough handling, so high-quality versions should be used to ensure reliability.



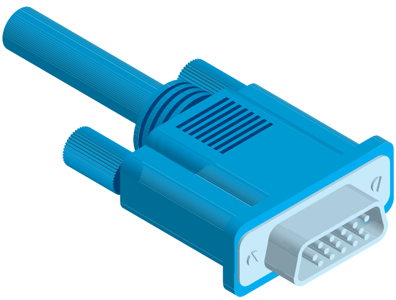
Circular Connectors:

This type of connector is regularly specified for a variety of industrial and commercial applications that require a highly reliable interconnect and ingress protection against dust and fluids. The M8/M12 connector has established itself as a standard for industrial automation applications such as industrial Ethernet, motor-drive controls, and to connect sensors and actuators.



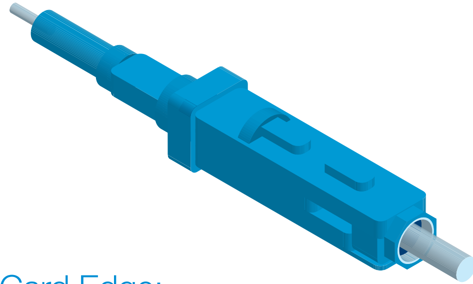
D-Sub:

This long-standing latching connector type can contain from two to more than 100 contacts per connector in up to four rows. It is available for chassis and direct PCB mount in standard and compact Micro-D versions for space-constrained applications. Wires can be crimped, soldered or IDC press-fitted. An extensive range of accessories is available to customise solutions. The DB-9 is popular for RS-232/RS-422 communications interfaces.



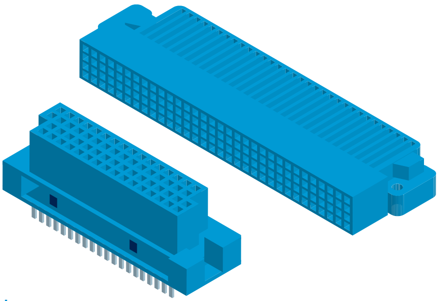
Fibre-Optic:

Used for high-speed, high-bandwidth applications, where signal integrity and data security are crucial. The fixed connector is usually female, and the cable is generally male. Inbuilt spring mechanisms ensure that glass or plastic conductors mate properly. If used outdoors, a sealed type should be selected, or a sealing boot used.



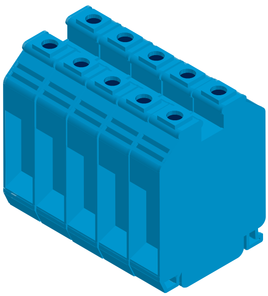
Backplane/Card Edge:

These are high-pin-count connectors for connecting PCBs to a common backplane, and are usually mounted at right angles to the PCB. DIN41612 is the most common standard, with male types used for the PCB and female types for the backplane. Options include specific contacts for power and long or short pins for sequencing power and signals during mating.



Terminal Blocks:

These are usually provided for equipment installers or users to connect discrete wires via a screw terminal or a press-to-clamp mechanism. They can be soldered directly to PCBs or clamped to a DIN rail, and available accessories include pluggable blocks for multi-wire connections. If used for hazardous voltages, selection of correctly rated types must be ensured.



Display Technology

Incorporating a display is now a prerequisite of almost every modern electronics design. Not only does this enable the presentation of information about the device's operation, but, in conjunction with a touchscreen controller, it yields a user interface from which to control the device. In this chapter, we investigate and compare different display technologies and how they work.

Liquid Crystal Displays

Liquid crystal displays (LCDs) are constructed using a layer of transparent liquid crystal material placed between two polarising filters. By applying a voltage across the liquid crystal layer, it changes the polarisation, and hence the amount of light passing through it. Polarisation is observed by looking through the LCD, which requires a light source. In practice, a reflector or light source, commonly referred to as a backlight, is placed behind the LCD.

The first generation of LCDs could only display a fixed range of symbols; for example, the numbers used on a calculator. However, the development of thin-film transistor (TFT) displays, which comprise a grid of transistors built into the display surface, has enabled individual pixels to be turned on and off. Using this approach allows the LCD screen to render much more detailed images. By combining individual pixels with coloured filters, to create RGB sub-pixels, LCDs can be used to deliver full-colour images. TFT-based screens are widely adopted for flatscreen TVs, mobile phones and computers, and more recently for the user interfaces in industrial equipment and medical instrumentation.

Cold cathode fluorescent lamps can provide the backlight source, or, increasingly, light-emitting diode (LED) emitters have become popular. LEDs consume much less power than the alternatives, and can provide a broader range of contrast by adjusting the light level based on the content of the displayed image. It is worth mentioning some potentially confusing terminology in use, particularly by TV manufacturers, for various types of LCDs. For several years now, TVs with so-called LED displays have been available. These are LCDs that use LEDs solely for their backlighting.

The key advantages of LCDs are that they are both lightweight and compact. They are also very energy efficient, which makes them well suited to portable electronic devices. Also, they are incredibly versatile and can be manufactured in almost any size or shape. Conversely, the main shortcomings of LCDs are their limited viewing angle and the lack of a completely black colour. Because the liquid crystals do not become fully opaque, some backlight may pass through, resulting in an off-black display. LCDs are also temperature-sensitive, suffering from a loss of brightness or contrast if they are too hot or too cold.

LED Displays

LED display technology initially consisted of small numbers of individual LED elements positioned on a substrate that allowed the display of a limited range of symbols. Initially, only green, yellow and red colours limited the range of available image colours. The invention of the blue LED in the 1990s allowed full-colour displays to benefit from using red, green and blue (RGB) LEDs.

The subsequent development of the organic LED (OLED) meant that arrays of tiny LEDs could create pixels on a screen, allowing detailed full-colour images to be displayed. Combining these with a matrix of TFTs to control each LED produced active-matrix OLED (AMOLED) displays, which in turn enabled the realisation of larger, faster displays that consume less power.

Capable of fabrication on a flexible plastic substrate rather than heavy, rigid and fragile glass, OLED displays have several significant advantages over LCD screens. The use of LEDs to create individual pixels provides a much better picture quality, with increased brightness, deeper contrast and a wider viewing angle. On average, OLEDs also consume significantly less power, and are soon expected to be cheaper than equivalent-sized LCDs thanks to improvements in the manufacturing process. Currently, the main disadvantage of OLEDs is that they can degrade over time. This degradation affects blue more than other colours, and may cause the colour balance to change, as well as the overall brightness.

Electronic Paper

Electronic paper (e-paper) or electronic ink (e-ink) displays are designed to mimic the appearance of ink on paper. The first practical implementation of e-ink technology used a layer of spherical beads – black on one side and white on the other. Each side has a corresponding electric charge, which means that, by applying a voltage, the beads can be rotated to show their dark or light side. Through a matrix of connections, changing the charge on individual pixels switches them to black or white. Once the voltage is removed, beads that have rotated remain in that alignment, meaning that an e-paper/e-ink display is permanent, requiring no power to maintain the displayed image. By contrast, LCD and OLED displays require power to maintain a rendered image. E-ink displays are very energy efficient and suit applications that do not require constant updating of the image.

Among the advantages of an e-paper/e-ink display are that they are easy to read, have a wide viewing angle and support very low-power operation. Also, most types of e-paper can be built on a flexible substrate. They can also be read using ambient light rather than requiring a built-in backlight. This makes them very well suited to e-books, supermarket shelf labelling and other relatively static display applications. The main disadvantage of the technology is that it is relatively slow, meaning it is not suitable for moving images or interactive user interfaces. It also suffers from ‘ghosting’, where a faint after-image is left on the white background when black pixels are cleared. Though this is temporary and can be removed by completely erasing and redrawing the displayed page, it can result in a noticeable flicker when pages are updated. Coloured e-paper displays are becoming available, but are currently very expensive.

Display Quality Issues

When manufacturing a display panel, there may be some defective pixels that are either permanently lit or unlit – referred to as ‘stuck’ or ‘dead’ pixels. A panel with a small number of defective pixels may still be considered usable, and manufacturers have different policies on how to handle displays that have defects. Such different policies can, of course, prove to be a point of conflict between suppliers and their customers. For some products, a defect-free screen might be essential. In other cases, a small number of defects may be acceptable – for example, if they are not close together and not in the centre of the screen.

To provide some clarity on this issue, the International Organization for Standardization (ISO) has defined several quality classes based on the number of each type of defect allowed per million pixels. The relevant standards are ISO 13406-2:2001, and the more recent ISO 9241-302, 303, 305 and 307:2008 standards. The ISO 13406 standard was originally applied to LCD screens but is now equally relevant to newer technologies such as OLED and e-paper.

Unfortunately, not all manufacturers adhere to the standards, considering them to be guidelines rather than mandatory, and some interpret the standards in different ways.

Touchscreen Technologies and Other Display Accessories

The use of a display integrated with a touchscreen forms a flexible, configurable and interactive human machine interface (HMI). Not only does this create a better user experience, but it is also advantageous from the OEM's perspective, since it offers greater design flexibility and convenience than buttons and switches, as well as enabling more attractive design concepts to be realised. There are four main types of touchscreen technology, each suited to different application scenarios and budgetary criteria.

Resistive Touchscreens

These have several layers, termed a 'stack-up', two of which are made of electrically resistive material with a gap separating them. Thin wires on each layer create an X/Y matrix configuration that is read by a microcontroller. When the screen is pressed, a contact is made between the two resistive layers and the location of the touch point can be detected. Resistive displays of this kind are often used in factory automation equipment and point-of-sale (PoS) units in retail because they are both low-cost and waterproof. They can be operated when wearing gloves or by using any blunt instrument such as a stylus. Although robust, resistive touchscreens can be damaged by contact with sharp objects. The multi-layer construction reduces visibility of the underlying display, and the sensitivity of resistive touchscreens is limited. These points all need to be considered when selecting touchscreen technology.

Infrared Touchscreens

Popular in the late 1960s and early 1970s, but now less common, infrared (IR) technology has been an economically viable and reasonably accurate means of implementing simple HMIs. Offering rapid responsiveness and a multi-touch capability, it works by casting beams of IR light over the surface of the screen. The beams are broken at certain X/Y coordinates if a touch point occurs. One of the main disadvantages of using an IR approach is that it requires the inclusion of a bezel, in which the IR LEDs and photodiodes involved in creating and/or detecting the IR beams are housed. This has an impact on the overall aesthetics of the system and can also make the touchscreen more difficult to clean. Also, IR touchscreen technology is not suitable for outdoor operation as its performance can be affected by extreme variations in light levels.

Surface Capacitive Touchscreens

Capacitive touchscreens use a sheet of glass with a transparent conducting layer applied to it. When this is touched, the conductivity of the user's skin changes the electrical properties of the conducting layer. By measuring the changes in capacitance across the screen using a matrix of X/Y wires, the point of touch can be determined. Unlike resistive technology, these screens are sensitive to touch, so no pressure is required. However, they cannot be operated while wearing gloves and need a specially designed stylus. The capacitive layer can be directly integrated into the LCD or LED display so there are fewer layers involved. This results in better visibility and greater accuracy than that delivered by resistive touchscreens.

Projected Capacitive Touchscreens

One of the issues common to surface capacitive and resistive touchscreens is that the detection mechanism is placed on the exterior of the product, making it less robust. Improving the robustness characteristics by placing the touch sensor behind a relatively thick protective screen led to the development of projected capacitive (PCAP) technology. PCAP-based touchscreens are suitable to be implemented in systems that are more environmentally demanding, such as industrial automation – where they could potentially be exposed to oil, grease and water ingress, as well as the effects of shocks and vibrations. Other applications include places where surfaces need to be cleaned on a regular basis, such as in food processing and healthcare. Touchscreens employing certain types of PCAP technology can be activated even when wearing thick gloves, again making them highly appropriate for use in medical and industrial settings. Other advantages include support for multi-touch operation and gesture recognition.

A simple PCAP touchscreen consists of a layer of indium tin oxide (ITO) deposited on the underside of the glass screen. This is typically used in smartphones and other items of portable equipment that use small screens. It is very cost-effective, but not particularly scalable, since noise levels increase with touchscreen size. Larger form-factor PCAP touchscreens rely on a matrix of X/Y electrodes arranged to form grids, with the density of these grids defining the touchscreen's resolution. These will either use the principles of mutual capacitance or, conversely, self-capacitance – the latter proving more sensitive, while the former enables greater accuracy.

Additional Aspects

Additional features to consider when selecting touchscreen technology include the need for privacy filters, anti-glare film and optical bonding.

Privacy filters are of vital importance where private information might be displayed, such as bank account details on ATMs or patient records on monitors in hospitals. By applying a filter with louvres to the stack-up, the display's field of view (FOV) can be restricted so that only the user looking directly at the screen can see the information. For outdoor deployments such as public information systems or digital signage equipment, where the display is in direct sunlight, anti-glare/anti-reflection measures will need to be considered so the user can see what is on the display and touch appropriate parts of the screen accordingly. An anti-vandal coating might also be needed if the system is meant for unsupervised use in places where it could be at risk of damage. With optical bonding, a suitable adhesive is applied between the protective glass and the display surface, to remove the air gap. This improves the performance of the display or touchscreen assembly. It also makes the assembly sturdier, thus ensuring long-term operation, and eliminates the possibility of condensation building up on the underside of the protective glass, which could prove an irritation to users.

Power Semiconductors

In this chapter, we investigate some of the discrete and IC semiconductor devices used for power conversion and power management functions in modern electronic equipment. They vary in complexity, from simple two-terminal diodes, to three-terminal power transistors, through to multi-pin ICs used for power management.

Diodes

A diode is a semiconductor device whose function is to pass an electrical current in one direction only. Diodes are used for rectification, the process of converting an alternating current (AC) into a direct current (DC). Diodes are also used for a variety of switching functions. When specifying diodes, the key characteristics to consider are their current handling capability, the forward voltage drop during conduction, and the reverse voltage they can withstand. Of these three characteristics, the forward voltage drop is an important differentiator. The voltage drop is the difference between the input voltage and the output voltage, which results in power losses within the diode. Selecting a diode suitable for a particular application can sometimes be a trade-off between the forward voltage drop and the maximum reverse voltage the diode can withstand. Another type of diode is the Schottky diode, which is typically employed for high-speed switching tasks. Schottky diodes have a lower voltage drop compared to their silicon-based counterparts but cannot withstand such a high reverse voltage. Switching speed, or the rate of alternating between conducting and blocking, is another important parameter when selecting a diode. The Schottky diode is always fast, while silicon-based diodes are available in either slow or fast variants.

Thanks to recent semiconductor research, new materials such as silicon carbide (SiC) and gallium nitride (GaN) enable diodes to be produced with an improved combination of switching speed, temperature rating, reverse voltage and forward voltage drop. However, this improved performance comes at a higher unit price.

Another popular diode type used in power applications is the Zener diode. Typical functions for Zener diodes include use as a voltage reference or to clamp transient voltage spikes. Zener diodes block reverse current up to a specific voltage level; beyond that, they permit current to flow. When specifying such devices, the reverse breakdown voltage may be the deciding factor.

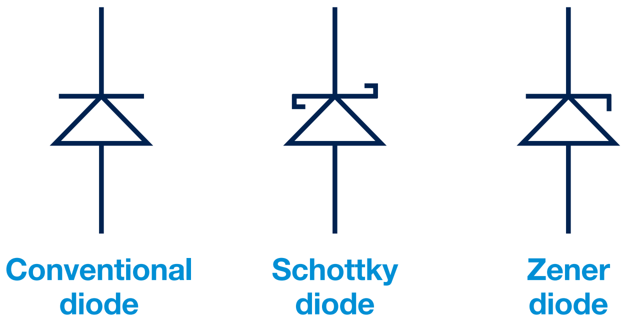


Figure 1: Main diode types

Power Transistors

In power applications, transistors typically act as controlled switches. They have three terminals, with a small signal being used on one pin to control a higher output current between the other two pins. The output current varies according to the adjustment of the input control signal. Alternatively, the transistor can act as a switch. In the latter case, a hard-off or -on output relates to a low or high input signal on the control pin.

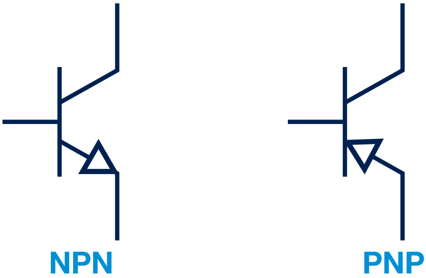


Figure 2: BJT types

Bipolar junction transistors (BJTs) suit low-power applications up to a few watts. Their control pin is termed the 'base' while the 'collector' and 'emitter' pins pass the controlled current. The primary specifications are the current or power rating, maximum operating voltage (also termed the breakdown voltage), the speed of operation, and current gain. The current gain is the ratio of the controlling input signal to the controlled output current. At high current levels, the power lost by supplying current into the base can be substantial. BJTs come in two main types, NPN or PNP, referring to the polarity of the controlling and switched voltages.

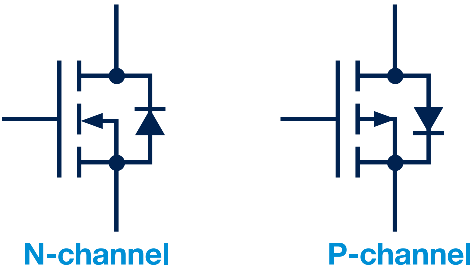


Figure 3: MOSFET types

Metal-oxide field-effect transistors (MOSFETs) are also three-terminal devices; the voltage on the controlling pin, termed a 'gate', controls the current passing through the 'drain' and 'source' terminals. Basic specifications are current handling, the breakdown voltage, and power handling capability. A key attribute, and one that is often a priority when sourcing MOSFETs, is the resistance between drain and source while conducting, denoted as $R_{DS(on)}$. It indicates the power loss that occurs within the device. Another parameter that needs consideration is the total gate charge $Q_{g(total)}$, as it quantifies the gate drive circuit losses during high-frequency switching. MOSFETs are preferred at high power levels because their losses are much lower than equivalent BJTs. Also, they can generally operate at higher frequencies.

The main MOSFET types are N-channel and P-channel, enhancement mode and depletion mode. These define the polarity of voltages used, and whether it is on or off like a switch. Unlike BJTs, MOSFETs can conduct in either direction between source and drain when on.

Insulated gate bipolar transistors (IGBTs) are a combination of BJTs and MOSFETs, with a gate pin controlling the current through the emitter and collector pins, much like in a BJT. An example of an older technology, IGBTs are only used as switches, not as 'linear' devices, and are relatively slow in operation, limiting their deployment to switching frequencies of around 50 kHz. Their power handling capability is excellent though, supporting currents of more than 400 A and voltages over 5 kV. IGBT applications include traction control, grid-tie inverters and high-power motor control.

Thyristors, sometimes called silicon-controlled rectifiers (SCRs), or triodes for alternating current (TRIACs), also feature in high-power circuit designs. These are latching semiconductor switches controlled by a gate pin. SCRs only conduct in one direction, while TRIACs can conduct in both directions.

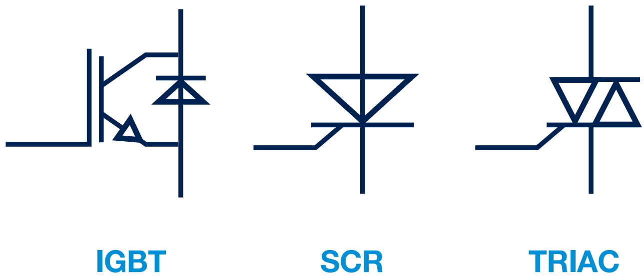


Figure 4: IGBTs, TRIACs and SCRs

Wide Bandgap Technologies

SiC and GaN are relatively new 'wide bandgap' compound semiconductor materials that are gaining in popularity. Such wide bandgap semiconductors deliver faster switching speeds, higher operating temperature levels, and considerably lower power losses than traditional silicon-based devices. They are more power-efficient, enhancing the performance of the end product. However, manufacturing costs are comparatively high, resulting in high unit costs. As adoption of wide bandgap devices grows, the unit price will most likely drop, driving their use in a broader range of applications.

Power Management ICs

In power electronics, general-purpose ICs are used for many different functions but primarily for control of the power conversion process: AC-DC, DC-DC, AC-AC or DC-AC. There are several different power conversion methods, termed topologies, in common use today: linear, buck and boost being the most popular. Each topology requires a slightly different method of control, with specific ICs available from numerous vendors.

Linear control ICs can just provide the control function or, alternatively, they can include the controlled or 'switching' transistor, such as a MOSFET. In switched-mode power conversion, control ICs are used to drive power transistors, which, for low- to medium-power designs, are integrated within the IC. Sometimes, multiple output channels are controlled simultaneously. In addition, many ICs are available that perform additional functions specific to power conversion and management, such as enabling a microcontroller to manage the operating parameters of the power supply and to alert the user to error conditions.

Power control ICs are categorised by their application as well as their electrical ratings. For example, there are ICs to manage the power conversion process and digital interface ICs to establish and maintain communication with a host microcontroller. Often there are equivalents between manufacturers, but if there is not a shared manufacturing licence, there are likely to be significant differences that could cause incompatibility. As a consequence, check before considering these as a potential second source.

Power Component Package Options

Although surface-mount packaging is commonplace, power components frequently use through-hole terminations to allow mounting on heatsinks as opposed to PCBs. However, as technology evolves and efficiencies increase, more power devices are available in gull-wing, ball-grid array, land-grid array and other proprietary packages. Lower-power devices use standard SMD sizes, and there are often provisions in the package, such as copper pads, to dissipate excess heat into PCB tracking.

Thermal Management

As our product designs become ever more compact and space-constrained, the need to consider the sources of heat within a circuit becomes increasingly important. Small amounts of heat are generated by a wide range of components: from resistors through to integrated circuits. However, the most notable candidates are typically those involved in power conversion. Components such as power transistors and MOSFETs used in power supplies and motor controllers demand particular attention. In servers and high-end computers, the processor ICs also generate significant amounts of heat. Minimising the amount of heat generated is achieved using energy-efficient components and power conversion topologies, but inevitably some form of thermal management is typically required. With the market trend to reduce size, weight and power (SWaP), careful selection of the right method of heat dissipation can be critical to the success of a product.

Thermal management methods fall into two main categories: passive, where the heat is conducted or radiated without moving parts, and active, where a fan or blower is used to create an airflow. Some applications use both passive and active methods of thermal management.

This chapter covers the most popular types of cooling, and some guidance is given on what to consider when purchasing thermal management solutions.

Heatsinks

As every application is different, it is no surprise that standard heatsinks are available in an almost limitless variety of sizes and shapes. In more specialist applications, there is also the option of designing a custom thermal management solution. Much like the cooling fins found on an air-cooled engine, a heatsink is a shaped piece of metal with heat-radiating fins that is attached to the device generating heat, such as a processor IC. Heat is absorbed through the heatsink base and then dissipated into the surrounding air through the fins, thereby cooling the device.

For standard semiconductor package types, including the TO-xxx packages commonly used by discrete, stud-mounted devices such as IGBTs, there are plenty of standard off-the-shelf heatsinks available. Microprocessors and other compute-intensive processors typically use ball-grid array (BGA) or land-grid array (LGA) package sizes, for which a wide range of heatsinks are also available. The semiconductor manufacturer and their distributors may also supply device-specific heatsinks.

When specifying a heatsink, there are some parameters to consider. The main attribute is the thermal resistance of the heatsink, measured in °C/W, which indicates how much the temperature of the heatsink will rise for each watt of heat that it needs to dissipate. Just about every aspect of a heatsink’s dimensions will impact this value, and, as always, trade-offs may be necessary to accommodate it within the available space.

Most heatsinks are made from aluminium, although aluminium alloys, copper and even ceramic heatsinks are also available. In general, the better the thermal performance, the higher the price, so it is always wise to specify the lowest performance material that meets the needs of the application comfortably.

The more surface area a heatsink has, the better it will dissipate heat. For this reason, heatsinks often have elaborate shapes, with fins, vanes and ridges used to increase the surface area for a given volume. Provided the heatsink will fit the available space, and the thermal resistance is adequate for the application, the shape or number of vanes is not a primary concern.

There are various methods of mounting heatsinks to a device, including screw mounting and the use of thermally conductive adhesives. While there may be only a small additional cost for the glue or screw, there can be a significant cost to production, due to the additional process step, and this should be kept in mind when selecting a heatsink. Safety is always a concern too. Where a surface might get very hot, appropriate warning labels are required, potentially further increasing the overall cost.

When mounting a heatsink, it is essential to ensure that no gaps exist between the device to be cooled and the heatsink mounting surface, as this will impair its effectiveness. The larger the surface, the more likely it is that this will be an issue, due to manufacturing tolerances. A range of thermal pastes and thermally conductive pads, often known as 'gap pads', assist in maintaining an excellent mechanical and thermal bond between the device and the heatsink.

Fans and Blowers

In applications where the heat generated is more than can be addressed through passive dissipation techniques, or where space constraints leave too little room for a heatsink, active devices such as fans or blowers are commonly employed. Fans and blowers are very similar; a blower is simply a fan with some form of cowling added to direct the airflow into a more controlled stream.

Fans can blow air over the cooling surfaces of a heatsink to increase heat dissipation, creating a more effective cooling mechanism, albeit at a cost.

The primary parameter for a fan or blower is the amount of air it can move. The airflow rate is most commonly specified as cubic feet per minute (CFM), although linear feet per minute (LFM) and metric equivalents are also used. The amount of air a fan or blower can move is dependent on several different parameters, such as the fan size and speed of rotation.

As active devices, fans require power to operate, from a few DC volts to mains AC voltages. Generally, it is best to select a fan that runs on a voltage supply readily available within the system. Generating a separate output voltage for the fan will introduce an additional power requirement, adding cost and, potentially, the need for more space. As fans consume power, they will also impinge on the overall system efficiency, which may impact the product's energy efficiency rating. If a fan is unavoidable, then modern brushless DC (BLDC) motor-based fans operate with greater efficiency than their brushed counterparts.

With several mechanical moving parts, fans and blowers can suffer from reliability issues and may fail before the electronics within the design. Fans need to be field-replaceable, although there are through-life cost and maintenance implications for the user.

In many applications, fans are speed-controlled to provide cooling only when the system operating temperature increases above a pre-set point. Some fans have integrated speed control, which saves space on the main PCB but increases the cost of the fan. If the fan is likely to be replaced during the life of the equipment, then including the control electronics on the main PCB and selecting the simplest fan type will help to reduce maintenance costs.

Fans can create noise when operating, the amount of which ranges from being almost unnoticeable, to becoming a real annoyance in some environments, for example offices or hospitals. In industrial or outdoor environments, this is much less likely to be of concern. Fans have a noise rating (dBA) so that quieter units can be specified if required. Of course, fans with lower noise ratings are generally slightly more expensive.

One downside of using a fan or blower is the potential to draw dust and debris into the equipment from the surrounding environment, thus leading to the premature failure of the system. Filters are usually available to prevent the ingress of dust particles, but that does increase costs and creates the need for a regular maintenance inspection. Safety is also a consideration with fans, due to the moving blades. Finger guards are a standard accessory, although punching slots into the product casing can avoid the cost of a guard.

Microcontrollers

A microcontroller is the principal component of any embedded system. Just like a microprocessor in a laptop computer, a microcontroller executes software that provides the system with its functionality – whether it is a smartphone, a washing machine or an engine management system.

The main difference between a microcontroller and a microprocessor is the amount of functionality integrated into the device. The microprocessor in your laptop relies on other external integrated circuits (ICs) to support it, such as memory, network interfaces and display drivers, usually mounted on the same PCB as the microprocessor. By contrast, the microcontroller (MCU) has most of its functionality integrated within the same silicon: the processor core, memory, interfaces, power management and a variety of other functions, depending on device specification. When combined with other essential features such as wireless communication and LCD drivers, a microcontroller is called a system-on-chip (SoC).

Figure 1 shows the block diagram of a typical microcontroller. It includes a processor core together with several different interfaces, Flash memory for storing the application software and SRAM for storing data.

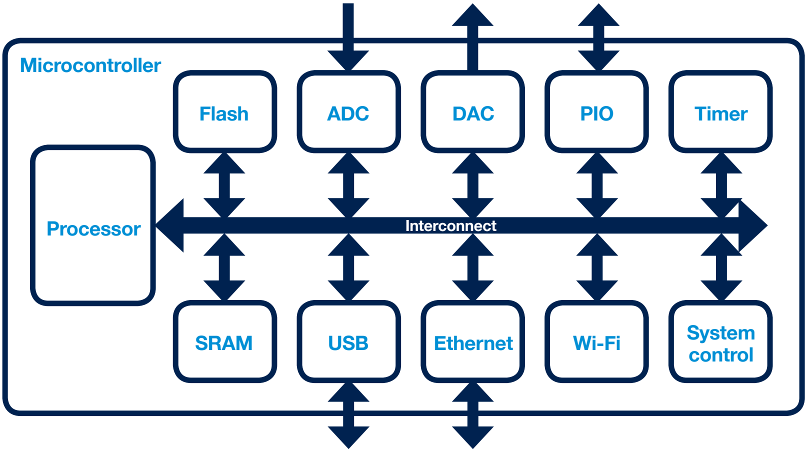


Figure 1: Schematic showing the basic functional blocks in a microcontroller

The peripherals of a microcontroller usually include a variety of interface options. These might consist of wired networking connectivity, such as Ethernet, or the support for wireless network protocols like Wi-Fi or Bluetooth. An analogue-to-digital converter (ADC) is used to provide a means of reading signals from an analogue sensor or for processing input from a microphone. Digital-to-analogue converter (DAC) interfaces are used to output audio signals or generate an analogue signal for a variety of applications. Input and output (I/O) connections, commonly called general-purpose I/O (GPIO), are used for connecting switches and LEDs, and serial interfaces such as USB are used to attach to and communicate with other application-specific sub-systems. Integrating more functionality into a single microcontroller device has a number of benefits. First, it helps reduce power consumption as processing data internally uses much less power than sending it externally. It is also much quicker to access memory if it is 'on-chip', thus providing a performance advantage. Furthermore, a more integrated approach significantly lowers the total system cost, because fewer additional components are needed.

There are several ways in which microcontrollers can be categorised. One is by the size of the digital 'word' the processor core, also termed the central processing unit (CPU), uses. The earliest and most widely used processors were 8-bit devices. These operate on data comprising eight individual binary bits, called bytes. Later processors used 16-bit, then 32-bit and 64-bit data. Eight-bit processors are smaller and can be lower-power and faster for some applications. For more complex applications, involving significant data processing, 32-bit or 64-bit processors will be more efficient. As technology has advanced, and processors have become smaller and more power efficient, there has been a steady move from 8-bit and 16-bit microcontrollers to 32-bit systems, which now make up over two-thirds of the overall microcontroller market. Eight-bit processors are still suitable for simple control applications, and heterogeneous processors use a mixture of 8-bit and 32-bit processors to suit specific requirements.

Another way of categorising microcontrollers is by the processor architecture. There are many different architectures used in embedded systems, but Intel (x86) and ARM dominate the market. They also have very different business models. Intel manufactures its own devices for embedded applications, and many of these use the low-power Atom processor. Meanwhile, ARM licenses its processor designs as intellectual property (IP) for other companies to use in their microcontroller designs. Companies that manufacture ARM-based microcontrollers include Microchip, NXP, STMicroelectronics and Texas Instruments.

The fact that many semiconductor manufacturers use the ARM architecture is an advantage for engineering and procurement teams. With many embedded developers using the same architecture, there is a good supply of software tools, applications, documentation and support available. The widespread use is also advantageous from a purchasing perspective, as it becomes a challenge for the semiconductor companies to differentiate their products away from the standard processor IP, thus maintaining competitive pricing.

For this reason, some companies, including many that are ARM licensees, have maintained their proprietary architectures. Some popular examples are:

- AVR, originally developed by Atmel, now part of Microchip. The Arduino development boards use the original 8-bit AVR processor. The 32-bit AVR processor is claimed to be exceptionally low power.
- The PIC family of processors from Microchip, initially designed in 1976. Since then a large number of devices with 8-, 16- or 32-bit processors and a wide range of memory and interface options have become available.
- The SuperH family from Renesas, which is particularly popular in Japan.
- Infineon's TriCore microcontrollers, which have features specifically designed for safety-critical applications, and so are widely used in automotive and industrial applications.
- The MIPS architecture from Imagination Technologies, which, like ARM, is licensed as IP.
- ARC, which is another IP processor design available from Synopsys.

But with so many microcontrollers available, what criteria are used to choose the best solution for a project?

First, the device must meet the basic requirements of the application in terms of performance, memory size, power consumption and integrated peripherals. That will still leave a wide choice of vendors with suitable products. Other factors to consider include the availability and cost of the software tools. To provide a competitive advantage, some semiconductor vendors have invested in developing integrated development environments (IDEs), offering these to customers free of charge, but there is also a wide range of third-party IDEs available. In some cases, the requirement for software compatibility will limit the choice of microcontroller. For example, if the device needs to run applications written for either ARM processors or the Intel x86 family, the choice is limited to compatible processors.

In the end, the decision may come down to something as simple as which hardware and software the engineering team has used the most. Previous expertise with a vendor's microcontroller can help reduce development time, and the risk of technical issues arising.

The nature of the product may also affect the choice. For example, a low-volume product might use an off-the-shelf single-board computer (SBC) that contains the microcontroller and all supporting hardware such as the power supply, interface sockets and an LCD. Although this approach has a higher unit cost, using an SBC avoids the cost of designing and manufacturing a custom board, resulting in a significantly shortened development cycle. On the other hand, for a mass-produced product, the volume pricing and availability will be critical.

In summary, the microcontroller provides the core functionality of an embedded system and will include all of the required memory and interfaces. With a wide range of products available, the selection process might appear complicated, but the expertise of the hardware team and project software requirements will shape the purchasing decision.

Data Converters

Microcontrollers are at the heart of most digital or embedded control systems. Microcontrollers process information digitally using 0s and 1s, where a low DC voltage, typically in the range of 1.8 V to 5 V, is used to represent a '1' value, and a lower voltage, usually less than 0.8 V, a digital '0'. Connections to other parts of the system, such as a USB interface, or a keyboard, are also achieved using digital words made up of sequences of 1s and 0s.

For interaction with the real-world environment, the microcontroller also needs to work with analogue signals. An analogue signal is composed of varying voltage levels across a wide dynamic range, and the frequency with which they vary can be equally complex. For the microcontroller to be able to process analogue signals, they first need to be converted into the digital domain. A familiar example is converting our speech into a digital signal so that a mobile phone can send it across the telephone network. At the receiving phone, it is converted from a stream of digital signals back into an analogue signal. Data converters are semiconductor devices that make signal transformations from digital to analogue and analogue to digital.

Digital-to-Analogue Converters

A digital-to-analogue converter (DAC) translates a digital value to the corresponding output voltage (or, in some cases, current). Because the input to the converter is digital, the output consists of a series of discrete levels rather than a smoothly changing voltage. The signal can be filtered if necessary, to smooth out the steps, as shown in the diagram below.

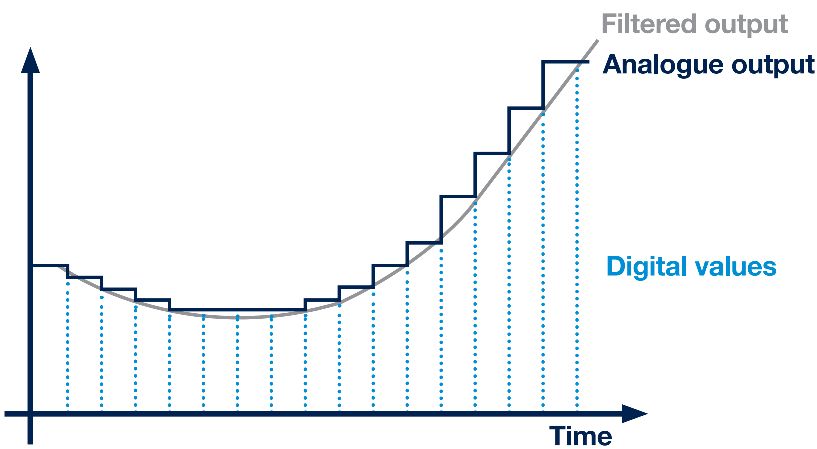


Figure 1: Example of a stepped signal being smoothed out through filtering

DACs find use in a wide range of different applications, one of which is generating audio outputs for use in digital music players, mobile phones and other consumer products. In these, the DAC device operates at a relatively low speed but requires very accurate conversion. Another everyday use for a DAC is generating the video signals inside a TV. There are many other applications such as controlling electrical hardware – for example, adjusting the voltage supply to a simple DC motor used for a cooling fan in a laptop changes its speed.

One of the simplest types of DAC circuitry generates a binary-weighted voltage for each bit of the input. These are then added together to give the output voltage. As an example, consider a 4-bit DAC that can output 16 different levels between 0 V and 1.5 V. Figure 2 shows how the value of 0101 creates a corresponding voltage.

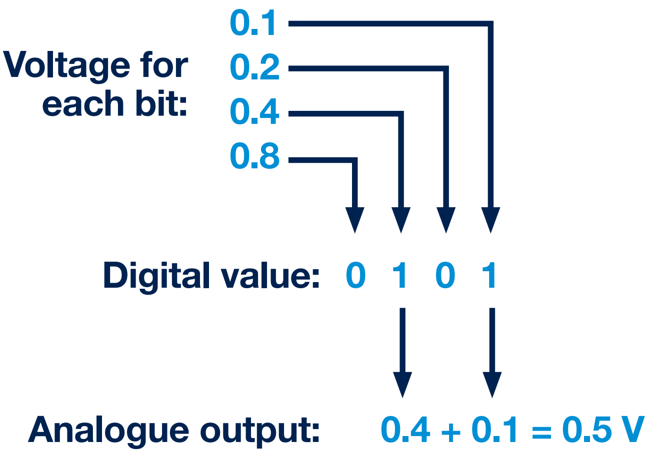


Figure 2: Conversion process on a 4-bit DAC device

An alternative way to create a pseudo-analogue signal is to use a technique called pulse-width modulation (PWM). In this case, the output is still a digital signal comprising a stream of 1 and 0 pulses. The ratio between the time that the output is a 1 (a high voltage) and a 0 (a low voltage) is varied so that the average corresponds to the required output voltage. If necessary, the output can be filtered to generate this average voltage; however, in many cases such as when driving a loudspeaker or motor, the device itself may act as a filter by smoothing out the pulses. Since a PWM signal exists in the digital domain, it is a low-cost and straightforward way of achieving a digital-to-analogue conversion.

Analogue-to-Digital Converters

An analogue-to-digital converter (ADC) transforms a voltage or current input signal to a digital number that represents its value. The process involves converting the varying input signal into a series of discrete samples taken at fixed time intervals. This approach may inevitably introduce some errors into the signal, as the continuously varying input is converted to a series of steps that are the nearest digital approximation of the input voltage.

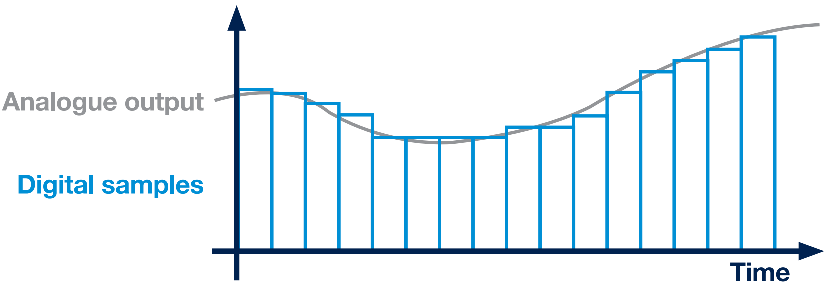


Figure 3: Example of an analogue signal transformed into a digital one

ADCs are frequently used for digitising audio signals, for example in music recording. Such an application requires accurate conversion of the analogue audio input signal to minimise noise and distortion that may otherwise be audible. An essential factor is to ensure the analogue signal is sampled at least twice as fast as the highest frequency in the input signal to avoid a problem called aliasing. Aliasing causes any frequencies higher than half the sampling frequency to appear as low-frequency noise. ADCs are also utilised for taking inputs from sensors, for example to measure temperature, humidity, light intensity or other physical properties.

Converting an analogue signal to a digital value is slightly more complicated than the other way around. As a result, there are many types of converter available, all with different characteristics. One of the most conceptually straightforward methods is called ‘direct conversion’. A direct conversion design uses an array of circuits to compare the input against each voltage range in the digital representation. Figure 4 shows how this works for a 2-bit ADC.

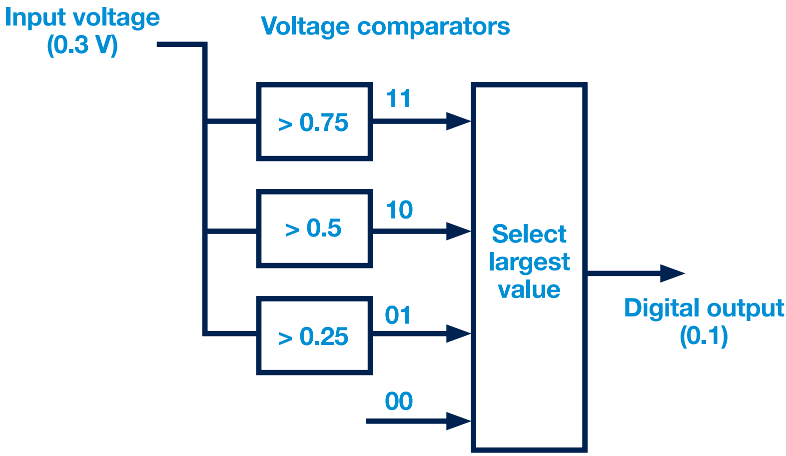


Figure 4: Schematic showing direct conversion on a 2-bit ADC

Although direct conversion allows high-speed operation, it quickly becomes expensive and impractical as more significant numbers of digital bits are required. The number of comparator circuits doubles for each extra bit added – so while 2 bits of data needs three comparators, 8 bits would call for 255. Architecting an ADC circuit based on this approach would result in a substantial bill-of-materials cost.

Other methods of analogue-to-digital conversion use time-based or iterative processes to find the digital value that matches the input voltage, for example counting how long an increasing reference voltage takes to reach the same level as the input signal. All these techniques have their respective trade-offs in terms of accuracy, speed and cost.

Quality and Performance

The resolution and speed of conversion are the principal attributes used to define the quality of an ADC or DAC.

Resolution is the number of discrete levels that the digital signal can represent (basically the number of bits in the digital value). For example, an 8-bit ADC can represent 256 different input levels (either as 0 to 255 or -128 to +127), while a 12-bit DAC can generate 4,096 different output voltages. Another way of considering resolution is in terms of the minimum step in voltage that can be detected or generated. The maximum resolution is determined by the accuracy of the components used in the converter and the level of noise exhibited, which both limit how small a difference in voltage is measurable. The second important aspect is the conversion speed and sampling rate – in other words, how frequently samples are taken and converted.

Specifying a Data Converter

Some microcontrollers have integrated ADCs or DACs, but for higher-quality or faster conversion, external ICs are likely to be used.

Because the analogue-to-digital circuitry is relatively complex, multi-channel ADC devices typically share a single converter between multiple analogue inputs. By switching each input channel to the converter circuit in turn, a corresponding digital value is generated. The resolution required depends on the accuracy required by the application. Any noise or distortion created by the inherent errors in conversion must be sufficiently small that they are not significant for the application. For simple temperature measurement, 8 bits may be adequate, and the sampling rate might be only once or twice a second. Sixteen- or 24-bit converters are ideal for high-quality audio conversion. As noted above, the conversion sampling rate must be at least twice as fast as the fastest input change. For professional-quality audio, this may be as high as 96 kHz. Handling video or radio signals may require even higher sampling rates. Not surprisingly, a high-speed 16-bit converter with high accuracy and low noise characteristics is likely to be more expensive than a slower, low-resolution device.

Operational Amplifiers

Operational amplifiers, universally known as op-amps, are incredibly versatile and popular general-purpose analogue components. With the addition of just a few external components, they form the basis of a wide range of different circuit designs.

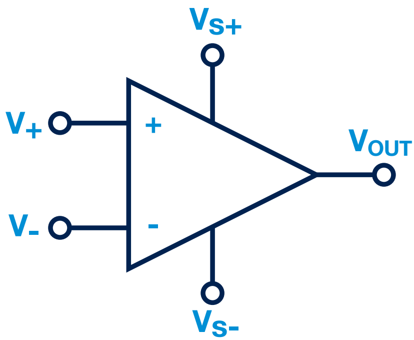


Figure 1: An operational amplifier

Op-Amp Overview

The basic op-amp is a high-gain amplifier with two inputs and a single output, as shown in Figure 1.

The gain of an amplifier is a ratio, expressed as V/mV (volts per millivolt), of the output signal compared to a given input signal. An op-amp gain, the amount the input voltage is increased to when measured at the output, can typically be in the order of 100,000. Such a significant gain means that even a small input signal, say 0.01 mV, can make the output go to a relatively high voltage value – in this case, 10 V, which is typically close to the positive or negative supply voltage. The gain achieved in this way is termed the 'open-loop gain'. By itself, this might not seem very useful, but we can use a technique called feedback to control the gain and also to change the op-amp's behaviour to make it more than a simple amplifier.

The op-amp has two inputs, which are termed inverting and non-inverting, usually labelled V- and V+. Applying a voltage to the inverting input causes a decrease in the output voltage. By comparison, a signal to the non-inverting input increases the output voltage. If the voltage on both inputs changes in the same way, there is no change in the output. The difference between the two inputs then determines the output voltage, hence the term 'differential amplifier'. This characteristic is useful because it allows the designer to use positive and negative feedback to control the circuit behaviour.

In most circuits using an op-amp, a proportion of the output voltage is connected back to the inverting input (as shown in Figure 2). This negative feedback can tend to counteract the changes in the output voltage. Consequently, the 'closed-loop' gain of the op-amp with negative feedback is much smaller than in the 'open-loop' condition, and depends on the amount of feedback. For example, if we use a resistor to feed back one-tenth of the output voltage, then the op-amp gain is 10.

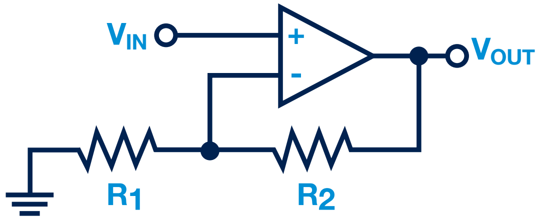


Figure 2: Using negative feedback to control the gain

In any practical circuit implementation, the external components connected to an op-amp determine the behaviour of the circuit. The impact of manufacturing variations of the device itself does not typically affect circuit performance. The specific details of a prospective op-amp can be used to model the likely behaviour of the initial design – typically done using SPICE software. Circuit analysis may involve, for example, adding additional external components to maintain smooth operation over the intended frequency range.

Possible Applications

Most op-amps are used in simple amplifier circuits, as shown above. Variations of the same circuit can be used to amplify signals from a microphone, for example, to invert a signal (V-), to measure the difference between signals (V+ and V-) or to sum signals by connecting them all to V+, via series resistors.

Identical signals applied to the inputs do not cause a change to the output, resulting in a characteristic termed 'common-mode rejection'. The ability to reject specific signals is essential because, in many applications, the common-mode component of an input signal is unwanted electrical noise. Such interference would be significantly reduced relative to the required differential signal. A variant of the basic op-amp that exploits this is the instrumentation amplifier. This amplifier configuration adds two further op-amps to the inputs to provide high common-mode rejection, making accurate low-noise measurements possible.

Another everyday use of op-amps is to build filters, for example to pass through or remove particular frequencies or frequency ranges. In this case, the feedback network includes other passive components, such as capacitors, whose behaviour is frequency-dependent. By feeding back more of the high-frequency components of a signal to the inverting input, the gain at those frequencies, and therefore their relative level in the output, can be decreased, producing a low-pass filter. Resistors and capacitors can also be connected to provide a time-dependent positive feedback source to build, for example, an oscillator function. Comparators, digital-to-analogue converters (DACs) and analogue-to-digital converters (ADCs) are other components that incorporate op-amps to provide a particular function.

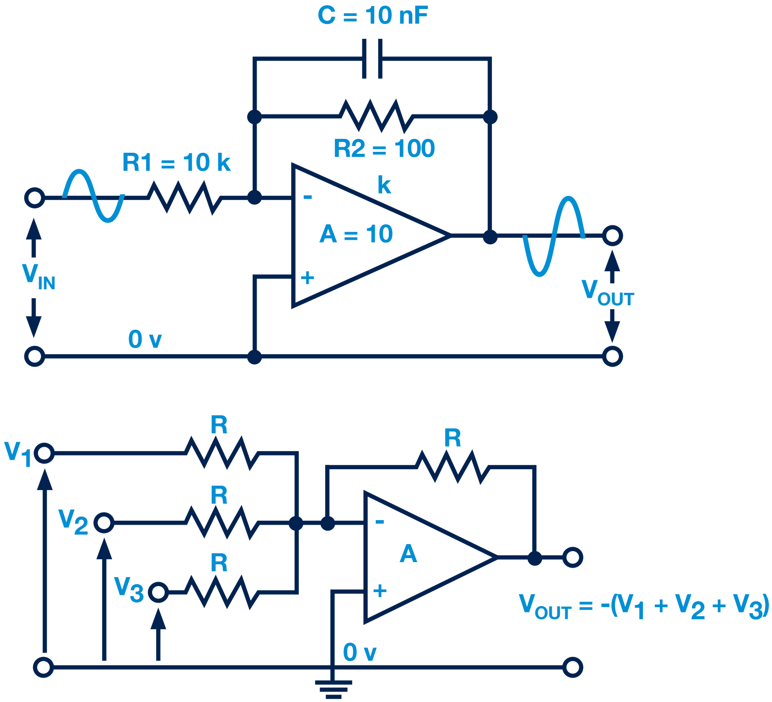


Figure 3: Low-pass filter and summing amplifier

Sourcing Op-Amps

Op-amp ICs may contain one or more op-amps in a single device package. The best-known op-amp IC is perhaps the '741', initially designed by semiconductor company Fairchild in 1968. Since then, there have been multiple versions designed by different vendors. The 741 is widely known, forms a core component for every electronics student and has become a generic name for op-amps. Op-amp specifications have advanced over the years, resulting in a wide range of different op-amp types being available from many manufacturers. These include varieties designed for low cost, high speed, low noise or some combination of such factors. General-purpose op-amps can cost as little as €0.10 in volume. Conversely, devices for more specialised applications, such as very low noise or automotive-qualified parts, can cost several euros.

Op-amps are manufactured using a variety of different semiconductor process technologies, such as bipolar, JFET, CMOS and BiCMOS. These different technologies each have trade-offs that can make them suited to particular applications. For example, CMOS devices tend to be lower power, particularly at low speeds, and consume less current at the inputs. Any hardware development team spends time reviewing the specifications of potential devices to see which best fits a specific design before incorporating it into the BOM. In general, there are multiple suppliers of devices with very similar characteristics, so second sourcing should be a straightforward process.

Productivity Tools

High levels of productivity and efficiency are critical to the success of any manufacturing business. Maximising your output with the available resources, especially time, is essential to maintaining a competitive edge.

Thankfully, within the world of electronics, there are many tools available to assist with design, procurement and manufacturing. In this section, we'll highlight some of the productivity tools available from Mouser:

- Computer-aided design (CAD) resources
- BOM management – Forte, the intelligent BOM tool
- Ordering automation – API and EDI

These tools save time, simplify workflows, reduce risk and can even shorten time-to-market, directly impacting the commercial success of a business.

Computer-Aided Design (CAD) Resources

Any electronic design starts with the circuit diagram or 'schematic' – a map showing all the components and how they are connected.

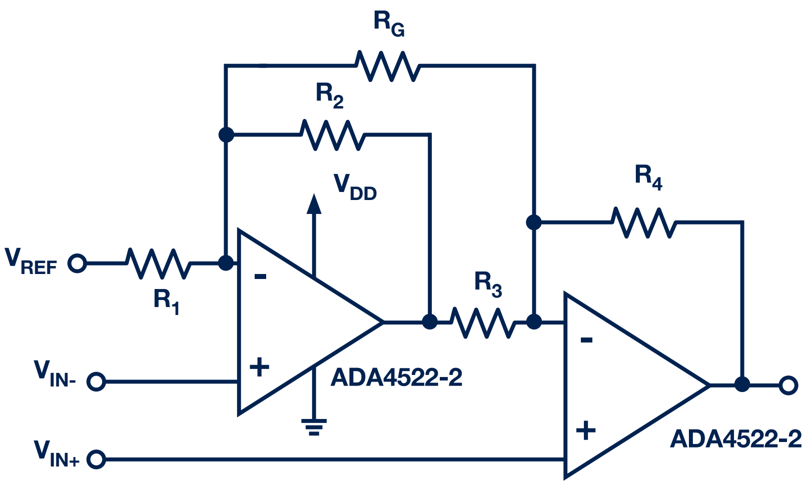


Figure 1: A typical schematic

Contemporary electronics design uses CAD software. This handles all the stages of circuit design, including:

- Drawing the schematic.
- Laying out the printed circuit board (PCB).
- Providing a list of components or ‘Bill of Materials’ (BOM).
- All files required for manufacturing and assembly.

Every design is different, and the number and type components will vary. Each must be represented accurately on the schematic with a symbol. The symbol describes the component type, the package it comes in and how it connects to other components. For an engineer, having access to a library of accurate symbols simplifies and shortens the design process significantly.

Once the schematic diagram is complete, the design moves to PCB layout. The PCB holds the components in place and provides the connection between them. In the same way that the schematic needs symbols, the PCB layout requires a ‘footprint’ that describes the physical space the components take up and where the connections are. Again, having access to a library of these pre-drawn footprints further simplifies and shortens the design process.

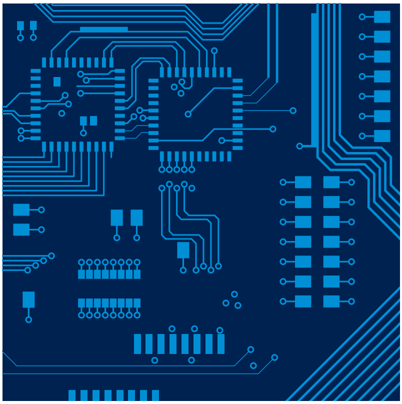
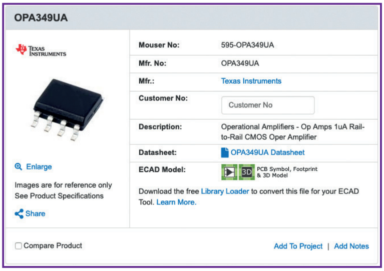


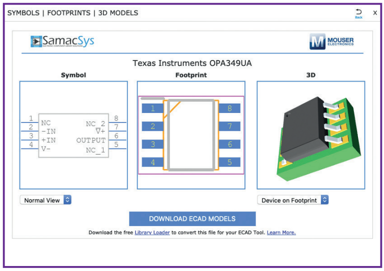
Figure 2: A typical PCB

In recent years, electronic design and mechanical design have converged, placing a greater emphasis on the need for 3D CAD models for components, too. These models enable product designers to understand the influence components have on the finished dimensions of a product, which is increasingly relevant given the drive for finished goods to be smaller and slimmer than ever.

Working with industry leader Samacsys, Mouser provides immediate access to symbols, footprints and 3D CAD models for components from hundreds of manufacturers.

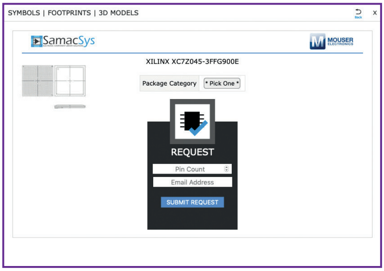
These resources are compatible with all leading design tools such as Altium, Pads, Mentor Graphics, Eagle and OrCAD, and enable the design engineer to preview available models before downloading them to their design and component library, free of charge.





Some designs will contain components for which models do not exist. Rather than having to create their symbol/footprint/3D CAD model, designers can request we build them.

This service is invaluable to engineers. Feedback suggests it can save as much as two weeks of design time while providing them with a verified model.



To learn more about saving time, simplifying your workflow and shortening your time-to-market, visit **mouser.com/ecad**.

BOM Management

In the previous section, we explained the use of CAD software for electronics design and how, among other things, it provides a BOM. Here we explore the critical role the BOM plays in the manufacturing process, and the benefits of using a BOM management tool.

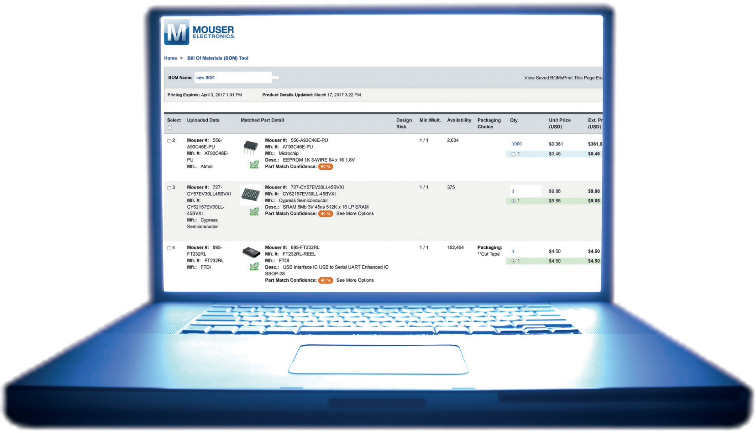
The BOM is a complete list of all the components on the board, including part number, manufacturer and the quantity required of each. Often this is supplemented with commercial information such as pricing, potential alternatives and lifecycle information.

For a simple project with a small number of components, manually managing the BOM may be adequate. As projects become increase in complexity, with hundreds of components, it can be impractical and inefficient to continue in this way.

Mouser's BOM tool, Forte, includes features to improve order accuracy, save time and increase confidence when specifying and purchasing components. BOMs from any CAD software can be easily imported and matched to the Mouser product range, providing:

- Price, packaging options and column breaks for ordering higher quantities.
- Stock availability and lead times.
- Part-match confidence level to ensure it's the right component.
- Alternatives if there is a second-source option.
- Design risk indication if a part is due to become obsolete.

Forte gives users the ability to change quantities and review pricing before requesting a quote or placing an order.



To learn how Forte, the intelligent BOM tool, can improve order accuracy, save time and reduce risk, visit **mouser.com/bomtool**.

Ordering Automation

Once the design is complete, the BOM compiled, and critical data included such as price, stock availability and lifecycle, the next step is placing the order for production.

For any business, managing a continual supply of components for a manufacturing process can be a complicated and time-consuming task. To assist with this, Mouser has developed multiple ways for you to integrate directly with our systems. Known collectively as 'Ordering Automation', this flexible service offers varying levels of integration depending on your need and system capability.

The primary methods are:

- Application programming Interface (API).
- Electronic data interface (EDI).
- PunchOut catalogue.

Application Programming Interface (API)

APIs are available to any customer and provide a flexible and adaptable connection for sharing data between applications or systems. At Mouser, we've created a suite of APIs that enable you to search, select and order products from within your applications, saving time and simplifying the overall process.

The APIs support three distinct functions:

- Product Search API easy access to product data, availability and pricing.
- Cart API – create and update your cart.
- Order API – review and submit your order.

Pricing and order rules are determined based on the billing address associated with your account and the default shipping address or the shipping address sent with the API request.

To learn how APIs can help you simplify your overall search, select and ordering process, visit **mouser.com/api-hub/**.

Electronic Data Interface (EDI)

Intended for customers with a large number of transactions, the deepest level of ordering automation is EDI. This standards-based data exchange protocol enables fully automated transactions between businesses, bringing significant advantages through:

- Increased processing speed.
- Reduced errors.
- Reduced cost.

To deploy an EDI solution, companies must first agree on which data exchange protocol to adopt, then commit resource on both sides for the duration of the project. Some typical protocols used are:

- EDIFACT.
- ANSI X12.

Implementation can be a substantial task, but it reflects the benefits of EDI where a business involves a large number of transactions across multiple locations. If in-house expertise is not available, several third parties are available to provide support. You may have MRP systems already capable of B2B EDI transactions, which should ease integration.

For more information about the benefits and implementation of EDI, visit **mouser.co.uk/order-automation/**.

PunchOut Catalogue

Also intended for customers with a large number of transactions, PunchOut Catalogue enables customers to purchase directly on the Mouser website from within their procurement system. Using cXML protocol, PunchOut Catalogue:

- Searches and adds to the cart directly on **mouser.com**.
- Creates pending purchase orders.
- Eliminates manual product data entry.
- Improves order accuracy.

When combined with EDI, the searching and buying process becomes entirely electronic, adding to the productivity and cost gains already associated with EDI. To learn more about the benefits of PunchOut Catalogue, visit **mouser.com/order-automation/**.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