Selecting signal switches to enable IoT communication modules

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Using signal switches to optimize IoT connectivity.

The Internet of Things (IoT) is undergoing tremendous growth and development as engineering communities from virtually every industry try to realize the benefits of the IoT concept. A similar growth trajectory is beginning to develop for the Industrial Internet of Things (IIoT). The IoT concept can transform existing applications into highly adaptive functions by connecting these applications to the outside world.

Overview

In addition to performing application-specific tasks, these functions also communicate the information they gather to a larger collective network. The network can then process the information and generate analytics and apply heuristics to continuously optimize the performance of the function.

Examples of attributes that can be optimized include power dissipation, response time, sensitivity, fault recovery and many others. In many cases, the performance enhancements that system designers wish to realize result in cost savings from lower system design costs. To a greater extent these enhancements allow a much lower cost of ownership or operation of the overall system.

The key to realizing the benefits of the IoT concept is connecting a function or process to a system's network. Connectivity plays a key role in almost all IoT implementations. Adding connectivity to a function requires a designer to balance multiple requirements such as power efficiency, flexibility, scalability, compatibility and cost. Given the wide variety of possible IoT implementations, some of these requirements will have greater importance than others depending on the application and its use case.

Connectivity for IoT often means that the application communicates with one or more networks using standard, proprietary or a combination of communication protocols and transmission methods. A simple example of the importance of connectivity in IoT is the modern smart utility meter. In the example shown in **Figure 1**, a modern smart meter connects to the utility company by way of a cellular or RF link as it also connects to the a home's Wi-Fi® network. This connection allows the homeowner to control and monitor the home AC unit and other electrical systems within the house. From this example, it is clear why IoT nodes like smart meters need to support multiple communication standards.

Communications standards such as *Bluetooth*® Smart (also called Bluetooth low energy), ZigBee®, near field communication (NFC), Z-Wave®, Thread, IPv6 over low-power wireless personal area networks (or 6LoWPAN), wired Ethernet, cellular and wireless Ethernet (Wi-Fi) are just a few of the standards that can be considered for adding connectivity to an IoT application. One of the hallmarks of IoT is that the connected functions

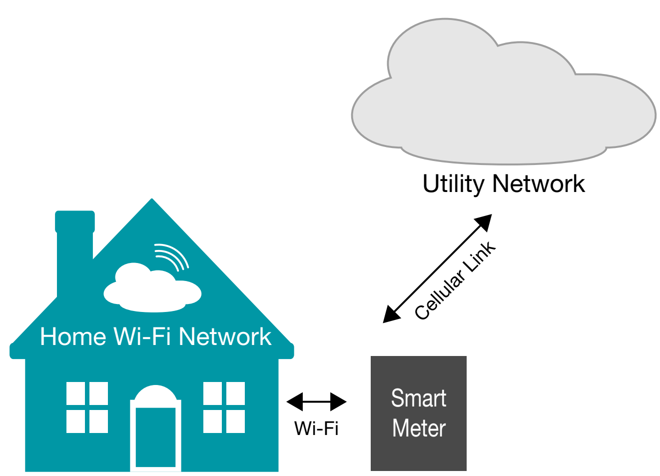


***Figure 1**. Modern smart meter supporting multiple communications links.*

are adaptive in terms of their ability to connect to different types of networks. This flexibility is achieved in many cases by implementing IoT functions that have the ability to communicate using multiple standards. Support for multiple communication paths means that the IoT node needs to support communication circuits that are specific to each standard.

Supporting multiple communications circuit paths within an IoT application presents special challenges to system designers. Implementing the communication links must be achieved while also balancing strict power, size, electromagnetic interference (EMI), and cost constraints that are typical of IoT field nodes. To manage these constraints, IoT designers have concentrated on designing highly optimized communication modules that implement specific communication links such as Bluetooth low energy or Wi-Fi.

An IoT implementation may incorporate multiple communication modules depending on the connectivity needed for the end application. To optimize usage of these different communication modules, IoT nodes often follow an algorithm where the IoT node switches to the appropriate communication module, activates it, performs the needed communications before switching to the next appropriate task. This basic approach enables IoT modules to remain power efficient while supporting multiple communication protocols. The key components that enable this type of design approach are simple signal switches (**Figure 2**).

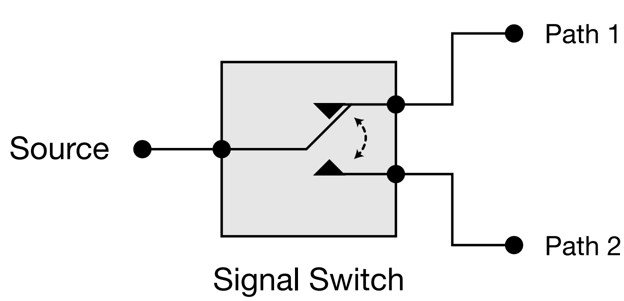


***Figure 2**. Block diagram of a simple signal switch.*

Signal switches have long been the key building blocks for many types of applications. Signal switches are used to re-route electrical signals to enable connector sharing, reduce duplicate circuitry, and optimize circuit board layouts. For IoT, signal switches allow smaller microcontrollers with one communication port to access multiple peripheral communications modules (**Figure 3**).

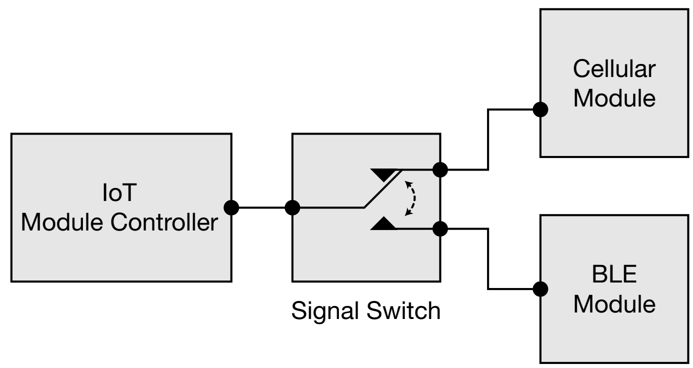


***Figure 3**. IoT node with two communication modules.*

Selecting the optimal signal switch for an IoT application involves aligning the key specifications for a given signal switch with the requirements of the IoT communication module that needs to be implemented. Key signal switch specifications that need to be considered are on resistance (R_{ON}), on capacitance (C_{ON}), charge injection (Q_C), bandwidth, leakage, isolation, configuration, turn off/on times (T_{OFF}/T_{ON}), and package type. Let us examine each of these specifications in more detail and how each one relates back to an IoT implementation.

Configuration

A switch configuration simply refers to how many connections can be made in a given switch. For example, a single-pole, single-throw switch (SPST) is the most basic type of configuration where the switch is open in one position and closed in another. Single-pole, double-throw (SPDT) is another common configuration where one switch position represents a specific signal path, while the other switched-position represents another signal path. **Figure 4** depicts three types of common switch configurations. For IoT applications, the switch configuration determines the number of communication modules a given system is able to support. For example, a single-pole, double-throw (SPDT) switch can support two communication modules while SPST can only support a single module. A single-pole, three-throw (SP3T) switch configuration can support up to three connection paths. The switch configuration should be one of the first consideration points when selecting a signal switch for IoT.

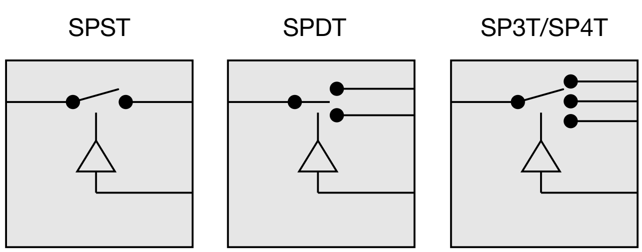


***Figure 4**. Examples of three common signal switch configurations.*

On resistance

The on resistance (R_{ON}) of a signal switch is the resistance introduced by the switch to the circuit when the switch is in the closed position. The on resistance value of the switch translates into multiple performance characteristics of a signal switch. For example, R_{ON} impacts the switch's power consumption, propagation delay, and the bandwidth of the signals that can pass through the switch without distortion. In most cases, lower R_{ON} values are preferred in order to achieve optimal performance.

Often designers want to use switches to accomplish simple signal re-routing; however, designers want to ensure that the impact of the physical switch to the signal itself is as small as possible. In essence, the best types of switches are the ones that have minimal impact on both the signal and the system while accomplishing their function.

Another important specification related to R_{ON} is R_{ON} flatness. R_{ON} flatness is a measure of how the R_{ON} changes over the operating voltage range of the switch. Note that R_{ON} flatness can vary dramatically, depending on the type of switch and its design characteristics. See **Figure 5** for R_{ON} and R_{ON} flatness comparison between a USB signal switch and a SPDT analog switch.

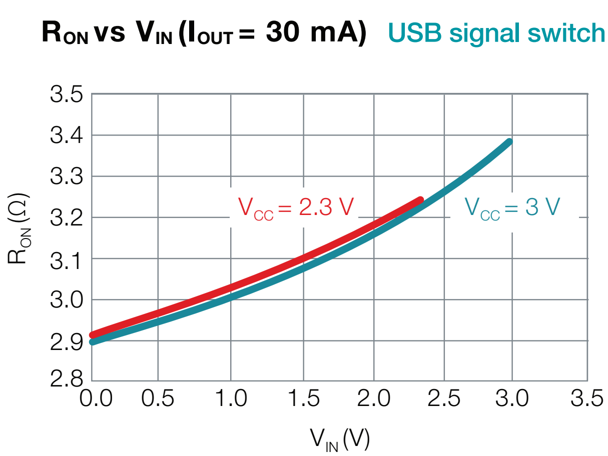
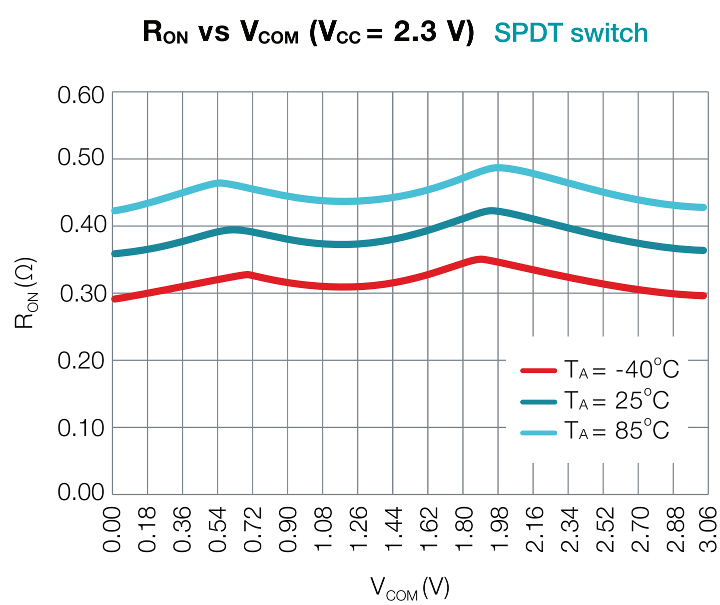


***Figure 5**. Example graphs of R_{ON} spec vs V_{IN}.*



For IoT applications that are very sensitive to R_{ON} shifts, select switches where the R_{ON} does not change drastically over the operating voltage range expected for that application. Do consider lower R_{ON} switches with relatively flat R_{ON} over voltage and temperature when selecting devices for IoT.

On capacitance

The on capacitance (C_{ON}) of a switch is the measure of the capacitance exhibited by the drain and source of the signal switch. For IoT communication module circuit links that are very sensitive to noise or have much lower noise tolerance, select switches with relatively better C_{ON} performance. This will help you to avoid unacceptable bit error rates (BER) for the application. A signal switch's data sheet will list values for on capacitances when the switch is in the open and closed positions. Lower values of on capacitance are preferable, especially as the signal's bandwidth starts to increase.

For IoT applications, you will need to balance the C_{ON} specification versus R_{ON}. For IoT nodes with enough signal noise margin, you may find it more beneficial to favor a signal switch with relatively lower R_{ON} than lower C_{ON} in order to optimize power dissipation of a communication module circuit that may be battery operated.

Charge injection

Many people familiar with switches are usually also familiar with the concept of on resistance (R_{ON}), however, fewer are familiar with a signal switch's charge injection (Q_C) property. In many cases, charge injection can be just as important for an application as R_{ON} and C_{ON}. Simply put, charge injection is a measure of the amount of charge that the switch can inject into the data path during a switching event. Charge injection is often stated in pico coulombs (pC) (**Figure 6**).

The injected charge can introduce noise into the data stream of the signal passing through the switch. The added noise can result in signaling errors that can cause a system to malfunction. The source and magnitude of the noise in the switch is highly dependent on factors, such as the transistor designs that make up the switch and silicon process technology used. For IoT communication module links that use single-ended signals or have very low signal thresholds, it is important to select a switch with relatively low charge injection in order to avoid data corruption during switching events.

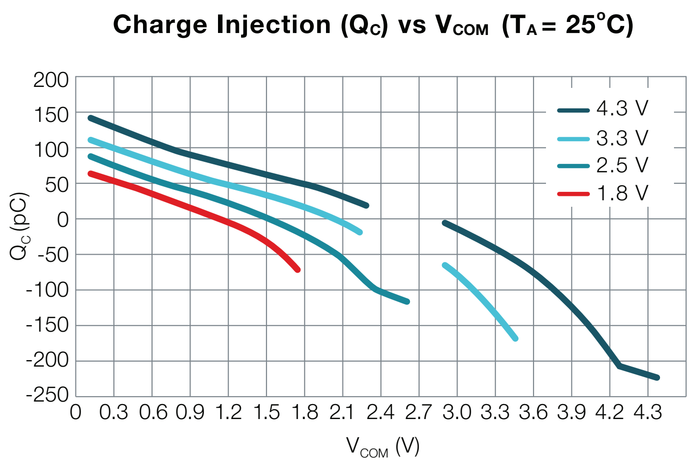


Figure 6. *Example of charge injection specification from a quad-SPDT switch.*

Bandwidth

The bandwidth of a signal switch is another important property to understand in order to ensure that a signal switch meets the target application's performance requirements. The bandwidth of a switch indicates the upper limit of the frequency (data rate) that signals passing through the switch can operate at without the signal being impaired. Understanding the bandwidth capability of a signal switch will help you to determine if the switch is suitable for the type of signal that needs to be switched.

Bandwidth is often specified in terms of a Hertz (frequency) nominal value, or a frequency range in KHz, MHz or GHz. It is common for a signal switch data sheet to have a graph of frequency versus gain to show how the bandwidth drops off over a frequency range. For IoT applications, bandwidth requirements tend to be on the low end of the frequency spectrum. Therefore, you may need to trade off bandwidth for another more important property, such as R_{ON}.

If an application is implementing a switch between ZigBee and Z-Wave modules and a microcontroller, for example, a switch with 500 kHz of bandwidth should be sufficient. **Table 1** shows the typical bandwidth and transmission ranges supported by different IoT communication standards. Consult the bandwidth graph of a signal switch to ensure there is sufficient bandwidth margin, especially for higher frequency IoT applications that may use Bluetooth low energy, Wi-Fi, or cellular communication modules.

Leakage

The leakage specification provides a measure of the power losses from the switch's drain and source. Leakage specifications are often provided in the signal switch data sheet for a switch in the open (off) and closed (on) states. For IoT applications, leakage is a critical specification as it directly impacts power consumption, which is critical for IoT nodes that are battery-powered. In addition to targeting low leakage signal switch devices for your application, you also need to make sure that the leakage stays consistent over temperature and voltage.

A signal switch with a nominal low leakage specification can become an issue if the leakage spikes at higher temperatures. **Table 2** contains an example of how to translate leakage current specifications that are provided in a signal switch data sheet to actual power dissipation. The calculation shows the worst case power lost from the COM pin leakage. Be prepared to perform multiple similar calculations to determine the overall leaked power loss for your particular signal switch.

Do not evaluate switch leakage as a standalone specification; but rather analyze leakage with reference to how the signal switch will be used in the application. For example, a signal switch with

	Bluetooth Smart (BLE)	Zigbee	Z-Wave	6LoWPAN	Thread	NFC	Wi-Fi	Wired Ethernet	Cellular
Range	50-150 m	10-100 m	30 m	10-30 m	30 m	10 cm	50 m	100 m+	35-200km
Data Rate	1 Mbps	250 kbps	9.6-100 kbps	250 kbps	250 kbps	100-420 kbps	150-200 Mbps	100 Mbps to 1 Gbps	100 kbps to 10 Mbps

Table 1. *Bandwidth and data transmission ranges are supported by well-known communication standards.*

		Condition	Temp	Voltage	Min	Nom	Max	Unit
ICOM(ON)	COM ON Leakage Current	V_{NC} or V_{NO} =Open, V_{COM}=1 V or V_{NC} or V_{NO} = Open, V_{COM} =4.5 V	25°C	5.5 V	-20	2	20	nA
			Full		-100		100	

Power = VI
V = Voltage in this case will be V_{CC} (testing condition)
I = Leakage current
Power loss (worst case) = (5.5 V - 1 V) * 100 nA = 450 nW/pin (for COM pin)

Table 2. *Example of translating the on leakage specification to power consumption. The leakage specification is derived from the TS5A23159 data sheet at V_{CC} = 5.5 V.*

very low off leakage and reasonable on leakage may be a better choice for an IoT application where the switch is off (open position) 99 percent of the time, versus a switch with average off leakage and very low on leakage. In fact, for most IoT applications in a quiescent state a majority of the time, switches with low off leakage should take precedence over on leakage performance.

Off isolation

The off isolation (O_{ISO}) specification for a switch provides a measure of how tolerant a switch is to noise passing through an open switch. Higher levels of off isolation are important in systems that are sensitive to noise coupling into the data path. The off isolation is typically specified in dB for a given frequency and loading (see **Figure 7**).

For IoT communication module implementations, selecting a signal switch with enough off isolation is critical in preventing noise from disconnected communication modules coupling into the data path. For example, in **Figure 3**, noise from the cellular module should not corrupt the Bluetooth low energy data path when the Bluetooth low energy data path switch is closed.

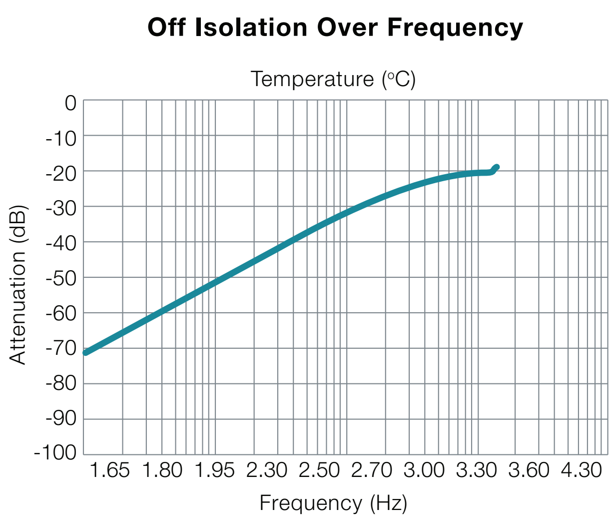


***Figure 7**. Example of off isolation curve from a quad-SPDT switch.*

Turn off/on time

The time to turn a signal switch from a disconnected state to a connected state is called turn on time (T_{ON}), while the time to turn a switch from a connected position to a disconnected position is called turn off time (T_{OFF}). Understanding the turn off and turn on times can be very important for a designer in order to ensure that system timing is not violated.

For example, in our reference IoT setup with Bluetooth low energy and cellular communication modules (see **Figure 3**), if the switch takes too long to move from one position to the other, then the microcontroller may end up sending data to a communication module while the switch is still transitioning from one position to another. In this case, the data will be lost resulting in a system error or the data having to be resent.

Carefully selecting a signal switch with turn off and turn on times that best suits the system's timing needs will go a long way in preventing system timing errors. It is also important to understand how much turn off and turn-on times vary by temperature and signal voltage. This is especially important for applications implemented in harsh industrial environments. An example of T_{ON}/T_{OFF} specification graphs over voltage and temperature is provided in **Figure 8** where (a) shows T_{ON}/T_{OFF} over supply voltage, and (b) shows T_{ON}/T_{OFF} times for the switch over temperature.

Package

The package size and type of a signal switch will determine how easily the switch can be integrated into the IoT node. For many IoT nodes, size is a paramount concern because the entire node itself is very small. Signal switches are available in many different package options including quad-flat no leads (QFN) and ball-grid array (BGA) packages that may be more suitable for certain IoT applications.

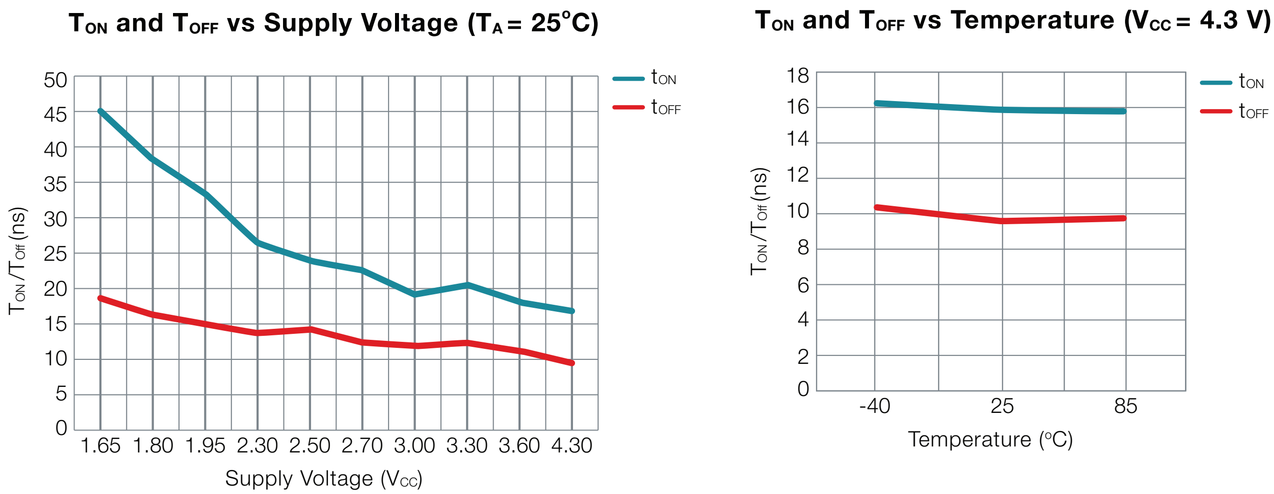


***Figure 8**. Example of T_{ON} and T_{OFF} curves from a quad-SPDT switch.*

For other IoT applications, the decision in selecting the signal switch package should be made in connection with other factors, such as module form factor, module signal layout, number of board layers, board level reliability requirements for the target operating environment, and other similar factors. Selecting the appropriate package and associated device pin out can help designers to simplify their signal routing to a great degree.

The example in **Figure 9** shows TI's TS3USB221A USB signal switch in the QFN package option, and its simple flow-through signal routing.

Conclusion

Simple signal switches play an important role in helping designers to implement IoT communication modules within their IoT node designs. Selecting the optimal signal switch for a given set of IoT communication modules involves understanding and relating the key specifications that define a signal switch to the target IoT application.

Designers often need to make tradeoffs between specifications in order to achieve optimal communication module switch performance for the target application. **Table 3** provides a relative guide in terms of importance of each of the specifications discussed for each of the common IoT communication standards. As designers from more end-equipment market spaces join the ranks of IoT implementers, selecting an optimal signal switch for an IoT module will become an important skill set that designers will need to possess.

Additional information

- Here is more information of signal switches.
- Download these data sheets: TS3USB221A, TS3A44159.

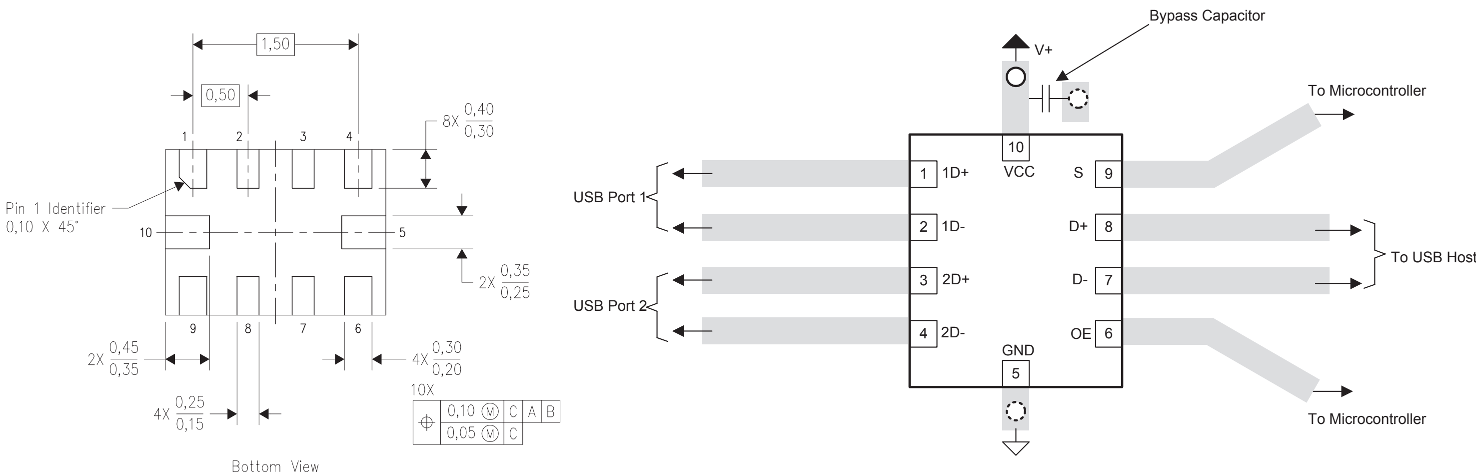


__Figure 9__. Example of a QFN package and signal routing: bottom view (a); top view (b).

	Bluetooth Smart	Zigbee	Z-Wave	6LoWPAN	Thread	NFC	Wi-Fi	Wired Ethernet	Cellular
On Resistance (R_{ON})	Red	Red	Red	Yellow	Red	Red	Yellow	Yellow	Yellow
On Capacitance (C_{ON})	Yellow	Yellow	Green	Yellow	Yellow	Green	Red	Red	Red
Charge Injection (Q_C)	Yellow	Red	Red	Red	Red	Red	Yellow	Yellow	Yellow
Bandwidth	Yellow	Green	Green	Yellow	Yellow	Green	Red	Red	Red
On Leakage	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Yellow	Red
Off Leakage	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow
Off Isolation	Yellow	Yellow	Red	Red	Red	Red	Yellow	Yellow	Yellow
Configuration	Yellow	Red	Red	Red	Red	Red	Yellow	Yellow	Yellow
T_{ON}/T_{OFF}	Red	Yellow	Yellow	Yellow	Yellow	Red	Green	Green	Yellow
Package	Red	Red	Red	Yellow	Red	Red	Yellow	Yellow	Yellow

Most important — Red
Moderately important — Yellow
Less important — Green

__Table 3__. Relative importance of signal switch specifications by standard.

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