Reliability vs. power in embedded wireless applications – What datasheets don't say

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Embedded wireless is simply the combination of an embedded process or system with a wireless interface for communicating. More specifically, these are the burgeoning systems enabling new forms of industrial, commercial and home building automation in addition to new capabilities and feature-rich products in consumer, medical and even agricultural systems. Power consumption, or rather the lack thereof, is a significant and in most cases, the driving requirement of all these low-data rate applications.

The measure of an embedded wireless application's power consumption, however, is not the simple sum of its parts as one might think. While this has been the typical means of comparing and selecting components for a given application, this basic means of obtaining a quantifiable metric to compare fails to adequately capture the true measure of how these components will interact and perform as a system. The focus must be on the wireless system's power consumption and how well a given wireless solution minimizes this costly resource. The often overlooked but equally important system attribute that drives down a wireless system's power consumption is reliability. Reliability, in this sense, is the measure of a system's ability to communicate data from point A to point B in a single attempt. This illustrates how reliability and power consumption in embedded wireless applications are related as well as how to optimize reliability and power efficiency.

Reliability as Related to Power Consumption

The most costly aspect in most embedded wireless applications, in terms of power consumption, is the transmit power of the transceiver components. There are many different transceiver components in the market today that when compared datasheet-to-datasheet offer relatively similar power ratings in the 20-30mA ranges—but if you stopped there and selected the lowest power rating of the components alone you might be overlooking the even more important system reliability attribute. Why does reliability matter? For a low-power application where every uA or mA counts, reliability is the singularly most important attribute in determining how often the application will remain at an active, high-power consuming state versus its extremely low-power, sleep state—the higher the reliability the less power is consumed. The ideal, perfect wireless system will transmit a set of data once and as fast as it possibly can to move data from point A to point B. Of course, no system will perfectly perform to this model all of the time and thus there will be retransmits due to interference or inadequate signal strength to reach remote end points—enter the quest for wireless reliability.

Wireless systems contain specific characteristics that can help qualify how well they will respond reliably in a given system such as *RF spectrum usage*—where, physically, in the RF spectrum do they communicate; *receive sensitivity* of the technology—how little do the transceivers need to hear in order to make out the communications, measured as a power ratio of decibels referenced to 1mW (dBm); *output power*—how loud can the technology communicate, ultimately talking louder than potential interference, measured in terms of dBm; *RF agility*—the measure of the ability of a technology to move and avoid interference in the RF spectrum, a corollary function of the RF channel size and the number of channels available; and finally, *interference immunity*—a RF technology's ability to communicate in a given channel despite interference as measured by an increase in receive sensitivity, also known as coding gain (dBm).

RF spectrum usage is a variable in the reliability equation dependent on environment due to the physical nature of RF waves. The lower the frequency, the larger the wavelength and thus the less prone to absorption by typical manufacturing materials such as liquids and reinforced concrete. That said, however, RF spectrum and its usage is a highly, governmentally regulated area of wireless communications to minimize interference with other wireless communications technologies. Only a few areas of the spectrum are reserved either locally or internationally for unlicensed use for these forms of communications, these are known as the Industrial, Scientific and Medical (ISM) band. Within this band, the predominant frequency that's accepted and used is the 2.4-GHz portion of the ISM band. In this frequency, though, the small wavelengths are quickly absorbed by the industrial space's hostile RF environment thus requiring even more focus on the remaining variables for measuring reliability.

Receive sensitivity, output power and even interference immunity can all be quantified together to form a larger, more important variable for defining reliability: link budget. Link budget is defined as the absolute value of the receive sensitivity plus output power and interference immunity. Therefore, the better the receive sensitivity, the larger the output power and the more interference immunity a solution has, the larger the link budget. The larger the link budget, the less prone the wireless solution will be impacted by RF absorption and interference and thus lead to greater potential for reliability.

Transceiver receive sensitivities and output power tend to be component-level discriminators that can be easily evaluated and compared against. Interference immunity, however, is largely a function of what types of technologies a wireless transceiver implements in order to improve its survivability. One of the best technologies in use today that directly improves this capability is Direct Sequence Spread Spectrum (DSSS) modulation.

DSSS modulation is essentially a method of performing forward error correction to the transmitting signal to minimize the impact of data loss due to signal interference. Specifically, DSSS encodes a set of data into a larger bit-stream based on a pseudorandom noise code shared by the transmitter and receiver. For example, in figure 1, 8-bits of data are encoded into 32 chips—in this case 4 chips are equivalent to 1 bit. The chips are then modulated onto the RF signal and transmitted. The receiver demodulates the chips off of the received signal and then reverses the DSSS encoding scheme. Even with demodulation errors due to signal noise or interference, the original data can still be recovered.

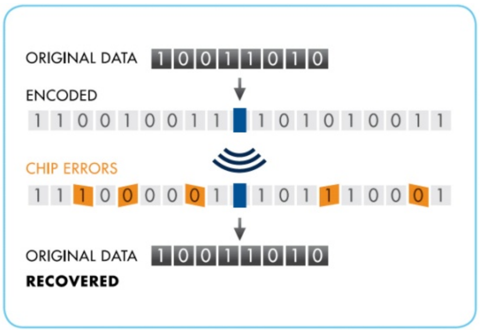

Figure 1 - Direct Sequence Spread Spectrum

Finally, RF agility improves reliability through interference avoidance techniques in terms of hopping or moving within the RF spectrum. The more freedom a solution has to move around the better able the solution will be to find and fit in a RF-quiet environment and receive less interference. Different RF-agile technologies in use today include pseudorandom or algorithm-based hopping schemes that continuously hop around the spectrum in the hope of minimizing interference as well as more intelligent schemes that only move when necessary (see figure 2).

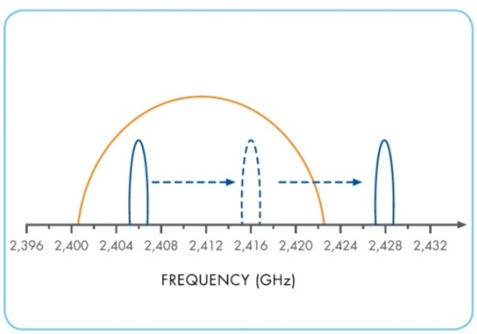

Figure 2 - Channel Hopping

The problem, from a reliability perspective, with the first agility scheme is that in a busy RF spectrum you may inadvertently continue hopping into portions of the spectrum which contain high-interference versus intelligence-based systems that will find a quiet location and stop moving. Regardless of the agility scheme, though, RF agility is equally a function of RF spectrum usage and channel-size. Depending on RF spectrum usage, you may have more or less room for this agility. For example, lower frequency solutions will have less room then higher frequencies due to frequency allocation constraints. 2.4-GHz solutions contain approximately 100-MHz of available spectrum while 900-MHz solutions only contain approximately 26-MHz of room. Channel-size is also a major factor in determining RF agility, the smaller the channel-size and the larger the room for agility in the spectrum, the greater your RF agility and ability to avoid interference and fit between interferers. For example, in the 2.4-GHz set of wireless solutions, 802.15.4-based solutions are typically 5-MHz wide and contain only 16 available channels while 1-MHz wide solutions typically have 80 available channels, thus more available places to move to and avoid interference.

Reliability, therefore, is the qualitative sum of link budget plus RF agility with respect to RF spectrum usage. The greater the link budget and the greater the RF agility, the more reliable a given wireless solution will be across the same RF spectrum. In addition, despite a solution having superior placement for a given environment in the RF spectrum, such as a lower frequency for a water-pipe filled factory, that same solution will still pale in comparison to higher frequency solutions that maximize link budget and RF agility. So, while not a quantifiable difference; it's easy to understand the logic that when comparing wireless solutions and ultimately their methods of maximizing system sleep time and conserving costly power.

Optimizing Reliability and Power Efficiency

Another new term to embedded wireless solutions is power efficiency, the measure of a system's passive and active techniques to minimize power consumption—the higher the efficiency the more power is conserved. A highly reliable system that spends most of its time in the lowest power consumption state, sleep mode, will typically be more power-efficient than other systems that may tout lower transmit and receive states but are less reliable because those systems will spend less time in sleep-mode. Reliability, therefore, is the leading indicator of how power-efficient a system truly is.

Reliability and power efficiency mechanisms work hand-in-hand to maximize power conservation but in addition to these mechanisms there are other techniques that can be employed that increase power efficiency with minimal effect on system reliability. These are system behaviors such as active link and power management which control dynamic data rates and output power levels. A solution that continually focuses on minimizing its output power to ensure only the lowest level necessary to communicate is used will not only be reliable but power-efficient by means of minimizing unnecessary output power. In addition, a solution that can adjust its data rate based on environmental conditions and minimize its on-air time will also minimize its system power consumption and boost its power efficiency. This form of power-efficient technologies, while not necessarily new to radio technologies, is new in terms of ensuring a system focuses on truly minimizing system power consumption.

Conclusion

Reliability, as we saw, is *the* leading indicator of how power-efficient a solution is and can also be optimized to maximize system sleep times and minimize on-air times. Finally, also presented was how our typical methods of comparing component datasheets fail to address system-level capabilities such as power-efficiency and reliability. Measuring typical power consumption of the components in use in the system, while is the more traditional means of comparing wireless solutions, however, does not tell the complete story of how well a particular solution minimizes system power consumption. For example, a highly reliable system that spends most of its time in the lowest power consumption state, sleep mode, will typically be more power-efficient and conserve the greatest amount of system power than other systems that tout lower transmit and receive power-levels but are less reliable. This again, is because those systems will spend less time in sleep-mode and more time retransmitting, or on the air.

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