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AN4004

Interference Mitigation Challenges And Solutions In The 2.4 To 2.5-Ghz ISM Band

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Associated Project: Yes

Associated Part Family: CYRF6936, CYRF6986

Software Version: NA

Related Application Notes: None

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As more products use 2.4-GHz ISM band of the radio spectrum, designers have to deal with increased interference signals from other sources. Regulations governing unlicensed parts of the spectrum state devices experience interference. This application note examines the various interference management techniques provided by the 2.4-GHz wireless systems and describes how to create frequency stability in a 2.4-GHz design using low cost tools.

Contents

Introduction

The main performance challenge for wireless devices is interference from other radio communication devices. Cypress's WirelessUSB 2.4-GHz radio system on a chip solution shares the 2.4-GHz unlicensed industrial, scientific, and medical (ISM) band with several other technologies. These technologies include 802.11b/g, bluetooth, 2.4-GHz cordless phones, microwave ovens, and other proprietary 2.4-GHz devices.

The WirelessUSB must coexist with these technologies, tolerating these interferences without causing them excessive degradation. This application note discusses how WirelessUSB LP/LPstar achieves these goals through interference avoidance. There are specific examples of the WirelessUSB LP/LPstar keyboard mouse reference design interaction with Wi-Fi, bluetooth, cordless phones, and microwave oven.

WirelessUSB LP/LPstar adds to the existing WirelessUSB portfolio, a low-cost wireless solution that uses the unlicensed 2.4-GHz ISM band. The 2.4-GHz ISM band is attractive to many technologies because it is available worldwide for low-power wireless communications. This application note assumes that the reader is familiar with WirelessUSB devices' operation.

How can designers get the best performance out of their 2.4-GHz solution under these hostile conditions? Often, the product works in a controlled lab environment but suffers performance degradation because of interferences from other 2.4-GHz solutions in the field. You cannot do more than what the architects of the Wi-Fi, Bluetooth, and ZigBee standards provide. But when the designer controls the protocol, there are procedures that help minimize the interference from other sources.

This application note examines the various interference management techniques provided by 2.4-GHz wireless systems and describes how low level tools are used to create frequency stability in a 2.4-GHz design.

Wi-Fi (802.11b)

The two methods for radio frequency modulation in the unlicensed 2.4-GHz ISM band are frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS). Bluetooth uses FHSS while WirelessUSB, 802.11b/g/a (commonly known as Wi-Fi), and 802.15.4 (known as ZigBee when combined with the upper networking layers) use DSSS. All of these technologies operate in the ISM frequency band (2.400–2.483 GHz) available worldwide.

Bluetooth

Bluetooth is used for ad hoc interoperability between cell phones, headsets, and PDAs. Most Bluetooth devices require regular recharging.

Bluetooth uses FHSS and splits the 2.4-GHz ISM band into 79 1-MHz channels. Bluetooth devices hop among these 79 channels 1600 times per second in a pseudo-random pattern. Connected Bluetooth devices are grouped into networks called piconets, each piconet contains one master and up to seven active slaves.

The channel hopping sequence of each piconet derives from the piconet master clock. All slave devices must remain synchronized with this clock.

Forward error correction (FEC) is used on all packet headers, by transmitting each bit in the header three times. A hamming code is also used to forward error correction of the data payload of some packet types. The hamming code adds an overhead of 50% on each data packet, but corrects all single errors and detects all double errors in each 15-bit code word (each 15-bit code word contains 10 bits of information).

Table 1. Various Technologies Occupying the 2.4-GHz ISM Band

2.4 GHz ISM Band Technology Comparison				
	Data Rate	Number of Channels	Interference Mitigation Method	Minimum Quiet Bandwidth Required
Wi-Fi (802.11b)	11 Mbps	3	Fixed Channel Collision Avoidance	22 MHz
Bluetooth	723 Kbps	79	Adaptive Frequency Hopping	15 MHz (Dynamic)
WirelessUSB	250 Kbps (DSSS)	79	Frequency Agility	1 MHz (Dynamic)
Zigbee	128 Kbps	16	Fixed Channel Collision Avoidance	3 MHz (Static)

WirelessUSB

WirelessUSB is primarily designed as a wireless option for computer input devices such as mouse and keyboards. It is also targeting the wireless sensor networks. WirelessUSB devices operate for months on alkaline batteries and require regular recharging.

WirelessUSB uses the DSSS frequency modulation instead of FHSS. Each WirelessUSB channel is 1 MHz wide, allowing WirelessUSB to split the 2.4-GHz ISM band into 79 1-MHz channels, similar to the Bluetooth. Unlike Bluetooth, WirelessUSB devices are frequency agile, that is, they use a fixed channel, but dynamically change channels if the link quality of the channel becomes suboptimal.

WirelessUSB uses pseudo-noise (PN) codes to encode each information bit. Most WirelessUSB systems use two 32 chip PN codes, allowing two information bits encoding in each 32 chip symbol. This scheme can correct up to three chip errors per symbol and can detect up to 10 chip errors per symbol. Although the use of 32 chip (and sometimes 64 chip) PN codes limits the data rate of WirelessUSB to 62.5 kbits (for LP only), data integrity is much higher than Bluetooth, especially in noisy environments.

ZigBee

ZigBee is designed as a standardized solution for sensor and control networks. Most ZigBee devices are extremely power-sensitive (thermostats, security sensors, and so on) and their battery life is measured in years.

ZigBee uses DSSS frequency modulation in the 868 MHz band in Europe, 915 MHz band in North America, and the 2.4-GHz ISM band for the rest of the world. In the 2.4-GHz ISM band, sixteen channels are defined, each channel occupies 3 MHz and channels are centered 5 MHz from each other, with a 2-MHz gap between pairs of channels.

ZigBee uses an 11-chip PN code, with four information bits encoded into each symbol giving it a maximum data rate of 128 Kbps. The physical and MAC layers are defined by the IEEE 802.15.4 Working Group and share many of the same design characteristics as the IEEE 802.11b standard.

2.4-GHz Cordless Phones

2.4-GHz cordless phones are popular in North America. Most of these phones use DSSS while some of them use FHSS. They do not use a standard networking technology. The phones using DSSS and other fixed channel algorithms typically have a channel button on the phone, allowing users to manually change the channel. FHSS phones do not have a channel button because they constantly change channels. Most 2.4-GHz cordless phones use a channel width of 5 to 10 MHz.

Collision Avoidance

It is also important to understand how each technology interacts in homogeneous and heterogeneous environments.

Wi-Fi's collision avoidance algorithm listens for a quiet channel before transmitting. This allows multiple Wi-Fi clients to efficiently communicate with a single Wi-Fi access point. If the Wi-Fi channel is noisy the Wi-Fi device randomly backs off before listening to the channel again. If the channel is still noisy the process is repeated until the channel is quiet. When the channel is quiet the Wi-Fi device begins transmission. If the channel is noisy even after repeated checks, the Wi-Fi device searches for other available access points on another channel.

Wi-Fi networks using the same or overlapping channels coexist because of the collision avoidance algorithm but the throughput of each network is reduced. If multiple networks are used in the same area it is best to use non-overlapping channels such as channels 1, 6, and 11. This allows each network to maximize its throughput because it does not share the bandwidth with another network.

Interference from Bluetooth is minimal due to the hopping nature of the Bluetooth transmission. If a Bluetooth device transmits in a frequency that overlaps with the Wi-Fi channel when a Wi-Fi device is in the “listen before transmit” mode. Then the Wi-Fi device randomly backs off while the Bluetooth device hops to a non overlapping channel allowing the Wi-Fi device to begin its transmission.

Interference from 2.4-GHz cordless phones can completely stop a Wi-Fi network; even if the cordless phones use FHSS as opposed to DSSS. This is partially due to the cordless phone’s wider channel (5 to 10 MHz) compared to Bluetooth (1 MHz) and also due to the higher power of the cordless phone signal. A FHSS cordless phone hopping into the middle of a Wi-Fi channel can corrupt the Wi-Fi transmission causing the Wi-Fi device to repeat its transmission. Do not use 2.4-GHz FHSS cordless phones close to Wi-Fi networks as they cause interference to all Wi-Fi devices. If the cordless phone is DSSS, you can eliminate the interference by configuring the channels used by the cordless phone and Wi-Fi access point to not overlap.

Handling Interference in Bluetooth

In Bluetooth, interference from other Bluetooth piconets is minimal, because each piconet uses its own pseudo-random frequency hopping pattern. If two co-located piconets are active, the probability of a collision is 1/79. The probability of a collision increases linearly with the number of co-located active piconets. Bluetooth originally relied on its frequency hopping algorithm to handle interference, but a single active Wi-Fi network can cause heavy interference on 25% of the Bluetooth channels. Packets lost due to overlap must be retransmitted on quiet channels, which adversely affects the throughput of Bluetooth devices.

Bluetooth specification version 1.2 addresses this issue by defining an adaptive frequency hopping (AFH) algorithm. This algorithm allows Bluetooth devices to mark channels as good, bad, or unknown. Bad channels in the frequency hopping pattern are replaced with good channels via a look up table. The Bluetooth master periodically listens to bad channels to determine if the interference has disappeared. If there is no interference, the channel is marked as good and is removed from the look up table. Bluetooth slaves, when requested by the master, also sends a report to the master informing the assessment of channel quality. For example, the slave may hear a Wi-Fi network while the master cannot. The Federal Communications Commission (FCC) requires at least fifteen different channels be used.

The AFH algorithm allows Bluetooth to avoid channels occupied by DSSS systems such as Wi-Fi and WirelessUSB. 2.4-GHz FHSS cordless phones may still cause interference with Bluetooth because both systems are operating over the entire 2.4-GHz ISM band. Because the Bluetooth signal is only 1 MHz wide the frequency of collisions between the FHSS cordless phone and Bluetooth is significantly less than the frequency of collisions between Wi-Fi and FHSS cordless phones.

Bluetooth also has three different packet lengths that translate into different dwell times on a given channel. Bluetooth has the option to reduce the packet length in an effort to increase data throughput reliability. In this scenario it is better to get smaller packets through at a slower data rate than losing larger packets at the normal data rate.

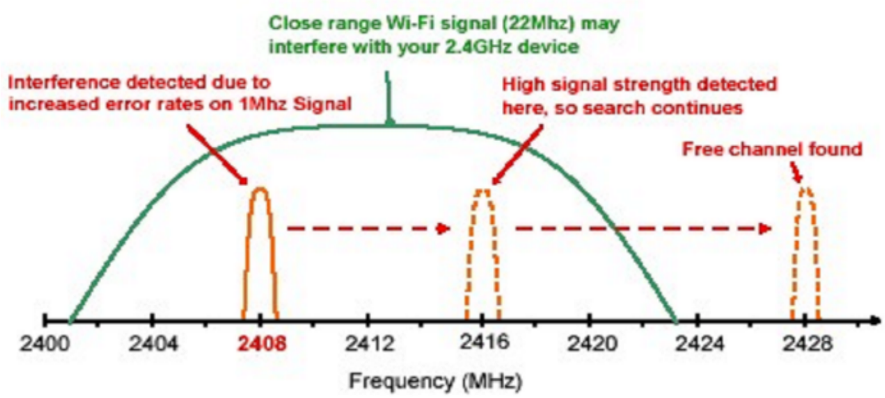
Handling Interference in WirelessUSB and ZigBee

In WirelessUSB, each network checks for other WirelessUSB networks before selecting a channel. Therefore interference from other WirelessUSB networks is minimal. WirelessUSB checks the noise level of the channel at least once every 50 ms. An interference from a Wi-Fi device causes consecutive high noise readings and the WirelessUSB master selects a new channel. WirelessUSB coexists with multiple Wi-Fi networks because WirelessUSB finds the quiet channels between the Wi-Fi networks as shown in Figure 1.

Interference from Bluetooth causes WirelessUSB to retransmit its packets. Due to the hopping nature of Bluetooth, WirelessUSB retransmissions do not collide with the Bluetooth transmission because the Bluetooth device moves on to a different channel. Bluetooth networks do not cause enough consecutive high noise readings for the WirelessUSB master to change channels.

ZigBee specifies a collision-avoidance algorithm similar to 802.11b; each device listens to the channel before transmitting to minimize the frequency of collisions between ZigBee devices. ZigBee does not change channels during heavy interference; instead, it relies upon its low duty cycle and collision-avoidance algorithms to minimize data loss caused by collisions. If ZigBee uses a channel that overlaps a heavily used Wi-Fi channel, field tests indicate that up to 20% of all ZigBee packets are retransmitted due to packet collisions.

Figure 1. WirelessUSB Channel Selection



What Can Be Done

When developing Bluetooth, Wi-Fi, or ZigBee, designers must use the methods provided in the specification. When developing a proprietary system based on 802.15.4, WirelessUSB or other 2.4-GHz radio, designers can use lower-level tools to create frequency agility.

DSSS systems are at the risk of overlapping with other DSSS systems. However, DSSS systems can obtain the frequency agility of FHSS systems in certain ways as described below

One such approach is network monitoring. If the DSSS system uses a polled protocol (where packets are expected at specified intervals) then the master can switch channels after a number of failed transmit attempts or bad received packets. Another approach is to read the energy level on the air if the radio has this capability. A receive strength signal indicator (RSSI) is used to measure the amount of energy on the air and if that level is too high over a period of time, switch to a clearer channel. A period of time is considered so as not to change channels if an FHSS system is passing through.

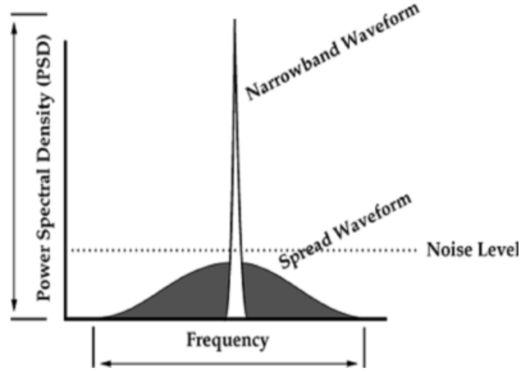
Network monitoring and RSSI readings assume that both radios are transceivers - they can transmit and receive packets. In a DSSS system where one side is a transmitter and the other side is a receiver, a multiple transmit approach is used to obtain frequency agility. The transmitter sends the same packet at multiple frequencies and the receives cycles through the receiver channels at a much slower rate. This system works when the receiver is connected to power and the battery powered transmitter is used less frequently. A wireless remote uses this approach.

Tolerating Interference

Direct Sequence Spread Spectrum

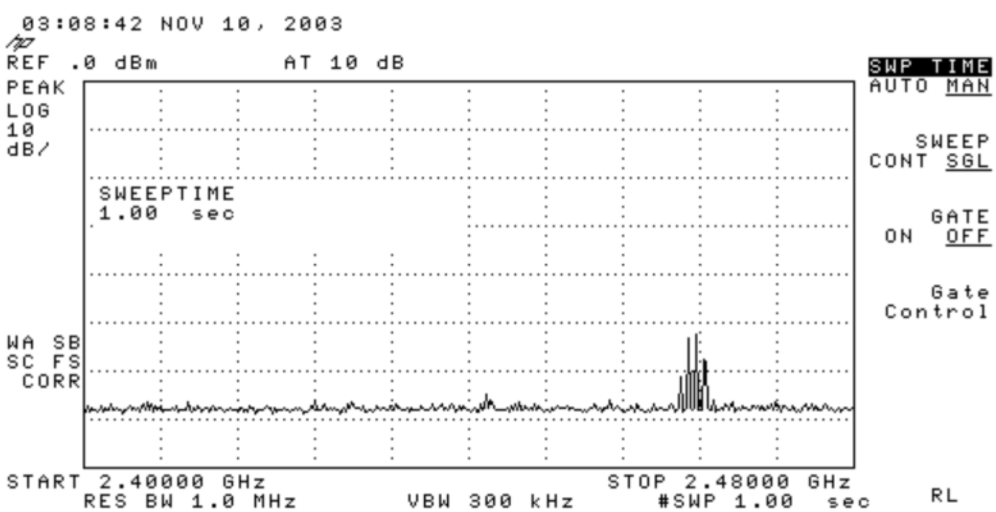
WirelessUSB LP/LPstar uses a Direct Sequence Spread Spectrum (DSSS) signal, which is shorter and wider than signals produced by traditional narrowband radios as shown in Figure 2. The wide bandwidth provided by DSSS signals allows WirelessUSB LP/LPstar to operate in noisy environments and reduces the interference caused by traditional narrowband signals

Figure 2. Spread Signal



WirelessUSB LP/LPstar splits the band into 78 distinct frequency channels, each channel being 1 MHz wide. The large number of channels allows many WirelessUSB LP/LPstar devices to be located in the same physical space and allows WirelessUSB LP/LPstar to find quiet channels between other signals. Figure 3 shows a WirelessUSB LP/LPstar signal captured on a spectrum analyzer.

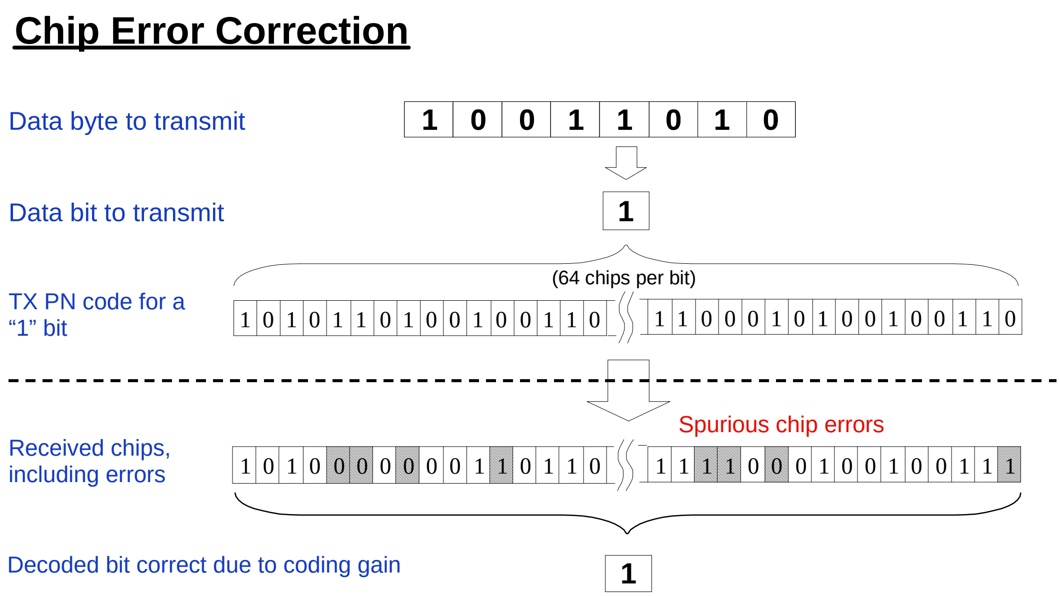
Figure 3. WirelessUSB LP/LPstar Signal in the 2.4-GHz ISM Band



Error Correction

DSSS systems transmits each data bit as a pseudo-noise (PN) code; each element of the PN code is called a chip. In the presence of interference (or near the limits of range), the transmitted PN code is often received with some corrupted PN code chips. DSSS receivers use a data correlator to decode the incoming data stream. If the number of chip errors is less than the correlator error threshold, the data is correctly received. It is therefore possible for WirelessUSB systems to successfully receive data without error on frequencies suffering from interference causing chip error rates in excess of 10 percent. Figure 4 shows a WirelessUSB LP 64-chip PN code example. WirelessUSB LP can use either 32 or 64 chip PN codes (LP star can only use 32-chip PN codes).

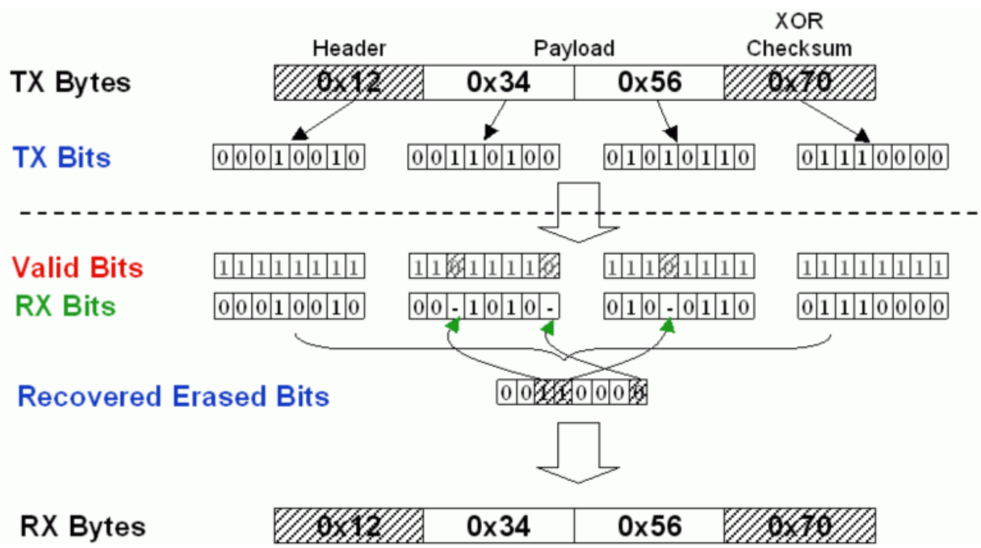
Figure 4. Chip Error Correction



If the correlator error threshold is exceeded, the received data bit is not corrupted but erased. There is a negligible probability of data being corrupted rather than erased, because this would require interference to corrupt the majority of chips in such a way that the incoming data stream correlated with the PN code corresponding to the opposite logic state. Erasures are much easier to correct than errors. By XORing each data byte and transmitting the resulting checksum as the last byte of each packet, it is possible to use this checksum to correct one error in each bit position in a received packet.

Figure 5 shows three corrupted bits being fixed using the XOR checksum.

Figure 5. Bit Error Correction



Frequency Agility

The robustness provided by using DSSS signals coupled with strong error correction, allows WirelessUSB LP/LPstar to operate in any environment. Strong interferences such as Wi-FI or cordless phones in close proximity to a WirelessUSB LP/LPstar system can cause excessive interference over sections of 2.4-GHz ISM band.

WirelessUSB LP/LPstar is designed to coexist with strong interferences by changing channels if the current channel suffers excessive interference. WirelessUSB LP/LPstar monitors the frequency of corrupted packets in order to determine the quality of the channel. If the frequency of corrupted packets exceeds the defined threshold then the WirelessUSB LP/LPstar system moves to a quieter channel.

Extremely strong interference on a channel can completely block the reception of WirelessUSB LP/LPstar signals. In such situations the corrupt packet frequency threshold is never reached because the receiver is unaware that packets are being transmitted. Therefore WirelessUSB LP/LPstar not only monitors the frequency of corrupt packets, but also periodically monitors the channel's signal strength. High channel signal strength indicates that there is a likelihood of a non-WirelessUSB LP/LPstar device transmitting on the channel. If the signal strength remains high for a defined period of time WirelessUSB LP/LPstar changes channels to a quieter channel. This allows WirelessUSB LP/LPstar to change channels in the presence of a strong interferer such as the Wi-Fi, but not change channels every time an FHSS device transmits a packet on the same channel as WirelessUSB LP/LPstar.

WirelessUSB LP/LPstar Interaction with Other 2.4-GHz Technologies

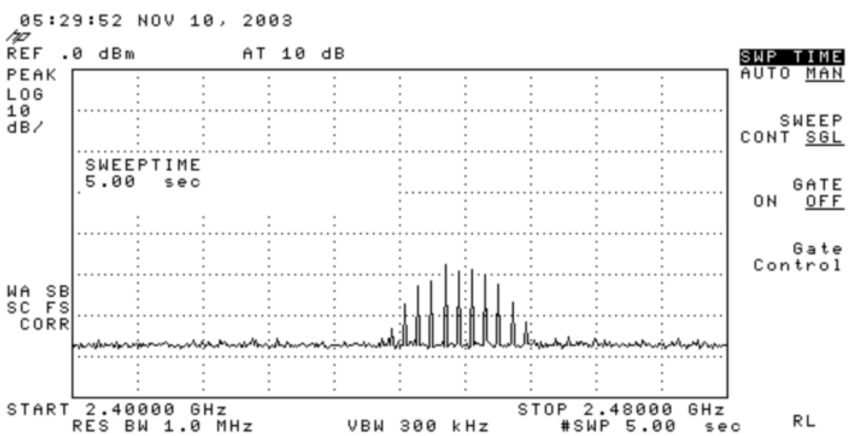
This section describes the characteristics of the most popular systems using the 2.4-GHz ISM band and how each system interacts with WirelessUSB LP/LPstar. Spectrum analyzer screenshots of each technology is provided showing the strength and width of each signal. Test results are also provided with description of the effects of each technology on WirelessUSB LP/LPstar.

802.11 (Wi-Fi)

Characteristics

802.11b and 802.11g are IEEE Wireless Local Area Network (WLAN) standards that operate in the 2.4-GHz ISM band and are also referred to as Wi-Fi. Wi-Fi uses a 22 MHz wide DSSS signal as shown in Figure 6. Up to three separate Wi-Fi networks can operate in the same physical space on different channels spread across the spectrum. Wi-Fi devices only change channels when the channel of the access point is manually changed (most access points provide a web interface for channel selection).

Figure 6. Wi-Fi Signal (5 s Capture)



Wi-Fi and WirelessUSB LP/LPstar Interaction

Configuration Details

Tests were performed using the following configurations:

One Wi-Fi Network

- One Wi-Fi access point located 10 meters from the WirelessUSB LP/LPstar Bridge.
- One Wi-Fi endpoint located within 0.25 meters of the WirelessUSB LP/LPstar Bridge (to simulate a laptop with both 802.11 and WirelessUSB LP/LPstar).
- One WirelessUSB LP/LPstar Mouse located 10 meters from the WirelessUSB LP/LPstar Bridge.

1.1.1.1.1 Two Wi-Fi Networks

- Two Wi-Fi access points on separate channels, located 10 meters from the WirelessUSB LP/LPstar Bridge.
- One Wi-Fi endpoint located 10 meters from the WirelessUSB LP/LPstar Bridge
- One Wi-Fi endpoint located within 0.25 meters of the WirelessUSB LP/LPstar Bridge (to simulate a laptop with both 802.11 and WirelessUSB LP/LPstar).
- One WirelessUSB LP/LPstar Mouse located 10 meters from the WirelessUSB LP/LPstar Bridge.

Three Wi-Fi Networks

- Three Wi-Fi access points on separate channels, located 10 meters from the WirelessUSB LP/LPstar Bridge.
- Two Wi-Fi endpoints located 10 meters from the WirelessUSB LP/LPstar Bridge.
- One Wi-Fi endpoint located within 0.25 meters of the WirelessUSB LP/LPstar Bridge (to simulate a laptop with both 802.11 and WirelessUSB LP/LPstar).
- One WirelessUSB LP/LPstar Mouse located 10 meters from the WirelessUSB LP/LPstar Bridge.

Pass Criteria

All tests passed with the following criteria:

- No perceived latency on WirelessUSB LP/LPstar Mouse.
- Less than 5% loss of data throughput on Wi-Fi networks.

Bluetooth

Characteristics

Bluetooth is a Wireless Personal Area Network (WPAN) standard that operates in the 2.4-GHz ISM band. Bluetooth uses Frequency Hopping Spread Spectrum (FHSS) signals that are similar to the narrowband waveform shown in Figure 2. However Bluetooth splits the 2.4-GHz ISM band into 78 channels (similar to WirelessUSB) and hops channels 1600 times per second using a pseudo random channel selection algorithm. Figure 7 shows a Bluetooth signal over 500 msec. Compare the width of the Bluetooth signal with the WirelessUSB LP/LPstar and Wi-Fi signals as shown in Figure 3 and Figure 6, respectively.

Figure 8 shows a Bluetooth signal over 5 seconds; note that the signal covers the entire 2.4-GHz ISM band.

Figure 7. Bluetooth (500 ms Capture)

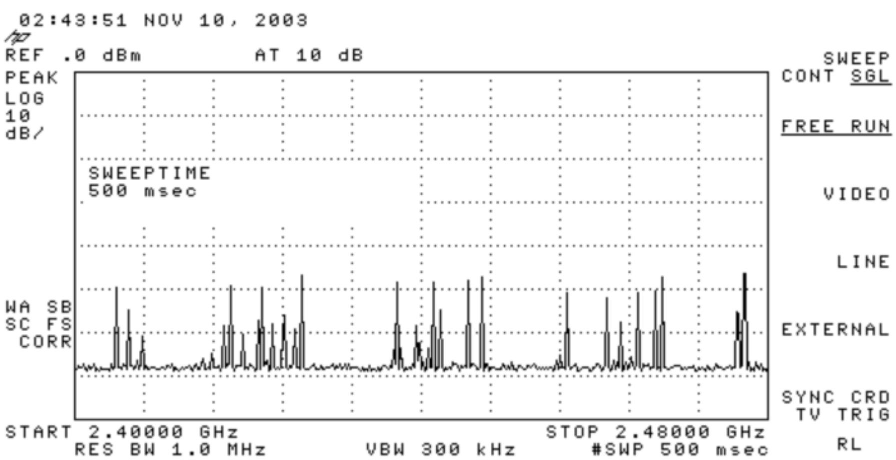
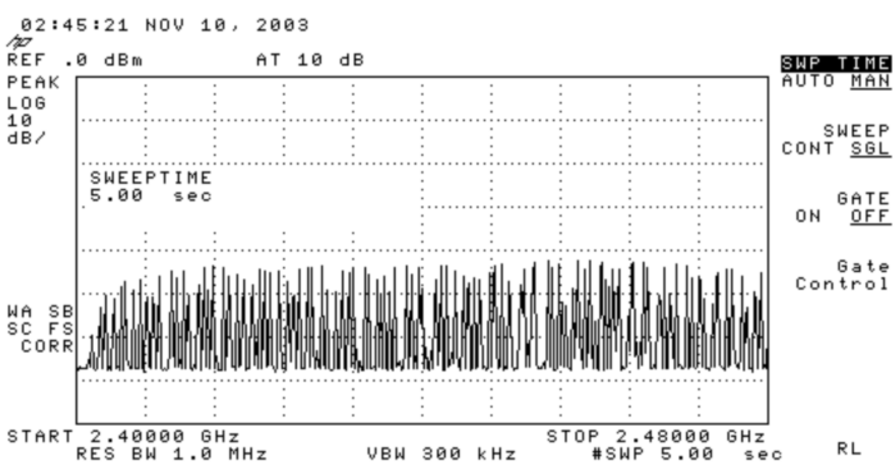


Figure 8. Bluetooth (5 s capture)



Bluetooth and WirelessUSB LP/LPstar Interaction

Although over 1% Bluetooth packets are transmitted on the same channel as WirelessUSB LP/LPstar, Bluetooth does not cause noticeable interference with WirelessUSB LP/LPstar. This is partially due to the lower duty cycle of the typical WirelessUSB LP/LPstar device and the robust error correction and retransmissions..

Configuration Details

Tests were performed with the following configurations:

- One Bluetooth device located 5 meters from the WirelessUSB LP/LPstar Bridge.
- One Bluetooth device located 0.25 meters from the WirelessUSB LP/LPstar Bridge (to simulate a laptop with both Bluetooth and WirelessUSB LP/LPstar).
- One WirelessUSB LP/LPstar Mouse located 10 meters from the WirelessUSB LP/LPstar Bridge.

Pass Criteria

All tests passed with the following criteria:

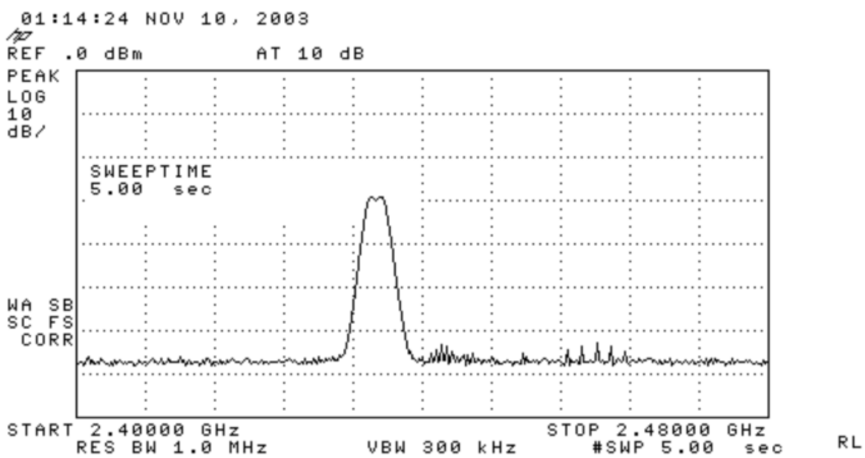
- No perceived latency on WirelessUSB LP/LPstar Mouse.
- Less than 5% loss of data throughput on the Bluetooth network.

DSSS Cordless Phones

Characteristics

There are a number of cordless phones that operate in the 2.4-GHz ISM band, some use DSSS and others FHSS. Panasonic and GE both have DSSS phones that produce a very strong signal as shown in Figure 9. These DSSS cordless phones only change channels when the channel button is pressed on the phone.

Figure 9. DSSS Cordless Phone (5 s Capture)



DSSS Cordless Phone and WirelessUSB LP/LPstar Interaction

WirelessUSB LP/LPstar coexists with DSSS cordless phones unless the 2 MHz of the middle of DSSS cordless phone signal overlaps the WirelessUSB LP/LPstar signal.

Figure 10 shows a DSSS cordless phone signal and a WirelessUSB LP/LPstar signal that do not interfere with each other.

Figure 10. DSSS Cordless Phone and WirelessUSB LP/LPstar

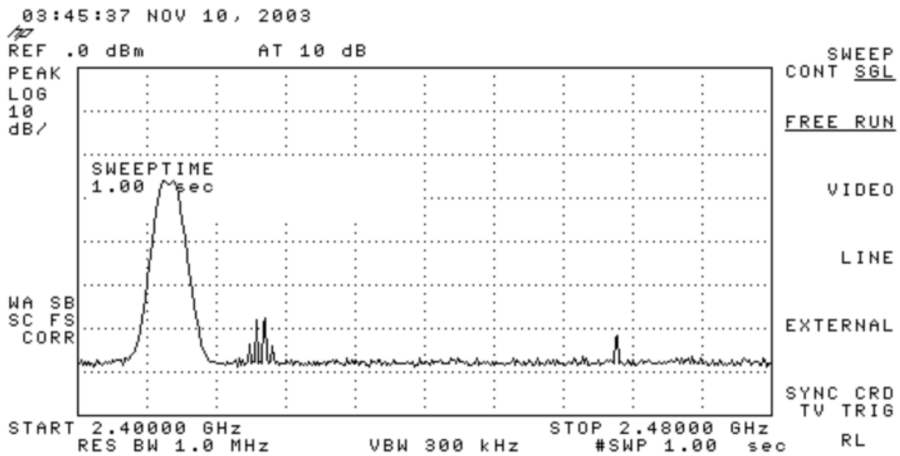


Figure 11 shows overlapping DSSS cordless phone and WirelessUSB LP/LPstar signals. In this situation the WirelessUSB LP/LPstar traffic is corrupted and the corrupt packet threshold monitor causes the WirelessUSB LP/LPstar devices to change channels and move away from the DSSS cordless phone signal. If the WirelessUSB LP/LPstar signal is covered by the DSSS cordless phone signal, the DSSS cordless phone signal completely blocks the WirelessUSB LP/LPstar signal. However, the RSSI threshold monitor triggers and cause the WirelessUSB LP/LPstar devices to change channels.

Figure 11. Overlapping DSSS Cordless Phone and WirelessUSB LP/LPstar Signals

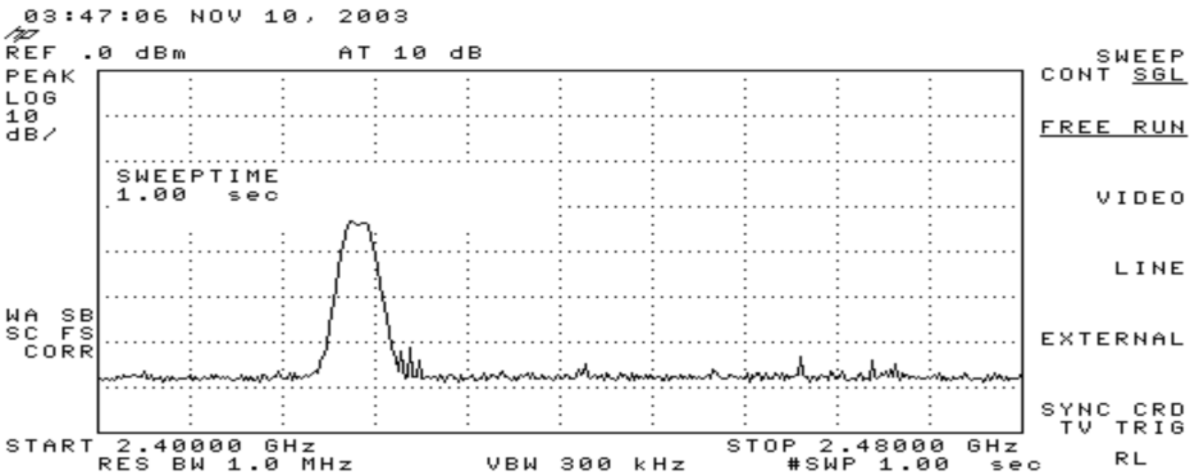


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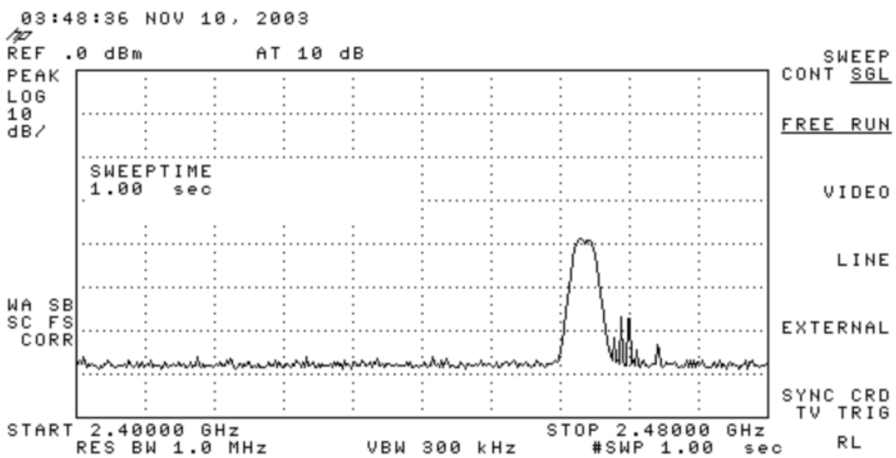
Figure 12 shows a DSSS cordless phone signal and a WirelessUSB LP/LPstar signal that slightly overlap, but not enough to cause interference. Both systems function normally without any loss of quality.

Figure 12. Non-Overlapping DSSS Cordless Phone and WirelessUSB LP/LPstar Signals



Configuration Details

Tests were performed with the following configurations:

- One DSSS Cordless Phone located 10 meters from the WirelessUSB LP/LPstar Bridge.
- One DSSS Cordless Phone located 1 meter from the WirelessUSB LP/LPstar Bridge (to simulate an office containing a DSSS Cordless Phone and a computer with WirelessUSB LP/LPstar).
- One WirelessUSB LP/LPstar Mouse located 10 meters from the WirelessUSB LP/LPstar Bridge.

Pass Criteria

All tests passed with the following criteria:

- No perceived latency on WirelessUSB LP/LPstar Mouse.
- No perceived loss of voice quality on DSSS Cordless Phone.

FHSS Cordless Phones

Characteristics

FHSS cordless phones hop frequencies similar to Bluetooth, but their signal strength is much higher than Bluetooth signals as shown in Figure 13. Note in Figure 14 that although the FHSS signal covers the entire 2.4-GHz ISM band over time, it is more sporadic than the Bluetooth signal as shown in Figure 8.

Figure 13. FHSS Cordless Phone (500 ms Capture)

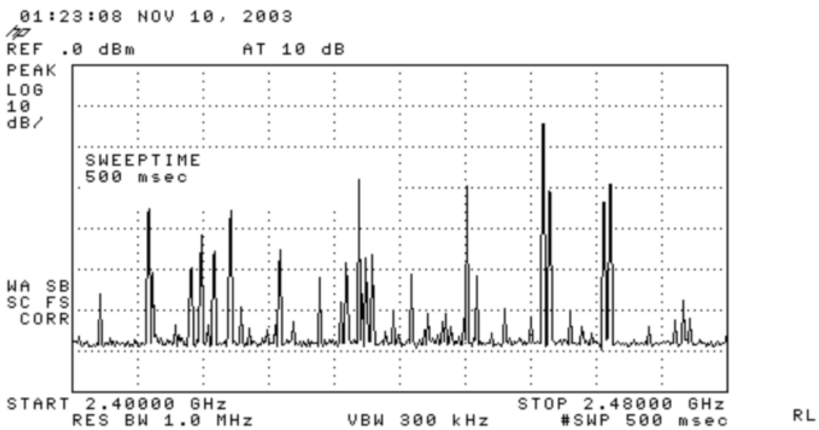
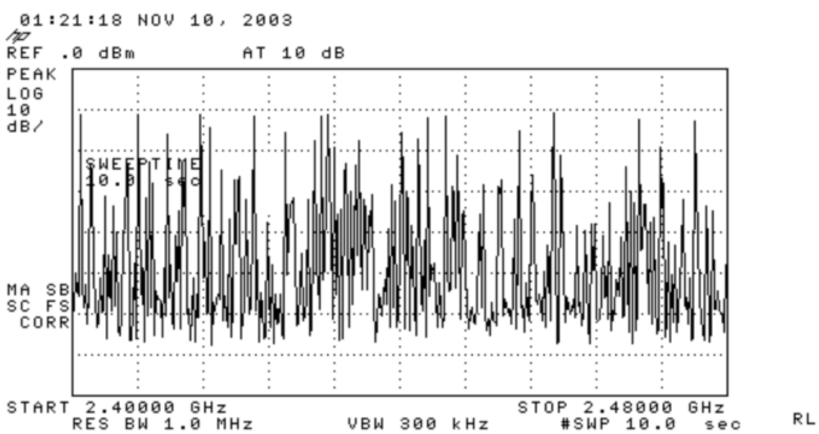


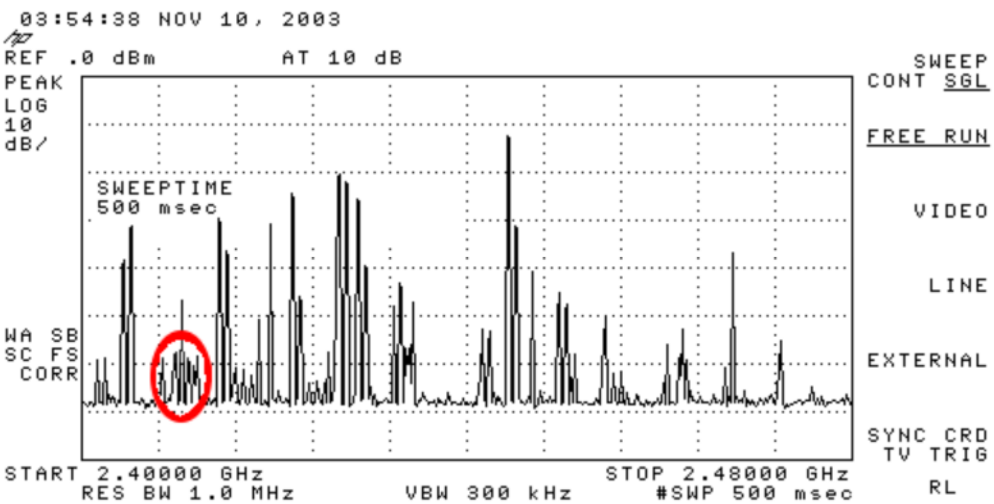
Figure 14. FHSS Cordless Phone (10 s Capture)



FHSS Cordless Phones and WirelessUSB LP/LPstar Interaction

FHSS cordless phone signals do not noticeably degrade WirelessUSB LP/LPstar signals, although they do cause packet retransmissions when the signals collide. This is because the FHSS cordless phone signal is much stronger than the WirelessUSB LP/LPstar signal. Figure 15 shows a FHSS cordless phone signal and a WirelessUSB LP/LPstar signal (shown in red).

Figure 15. FHSS Cordless Phone and WirelessUSB



Configuration Details

Tests were performed with the following configurations:

- One FHSS Cordless Phone located 10 meters from the WirelessUSB LP/LPstar Bridge.
- One FHSS Cordless Phone located 1 meter from the WirelessUSB LP/LPstar Bridge (to simulate an office containing a FHSS Cordless Phone and a computer with WirelessUSB LP/LPstar).
-
- One WirelessUSB LP/LPstar Mouse located 10 meters from the WirelessUSB LP/LPstar Bridge.

Pass Criteria

All tests passed with the following criteria:

- No perceived latency on WirelessUSB LP/LPstar Mouse.
- No perceived loss of voice quality on FHSS Cordless Phone.

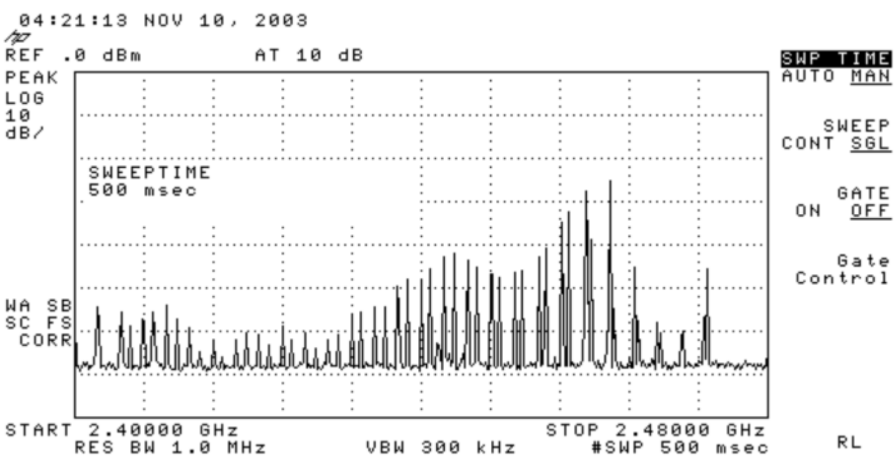
Microwave Ovens

Characteristics

Microwave ovens use 2.5 GHz radio waves to heat food because waves of this length are absorbed by water, fats, and sugar. The absorbed radio waves are converted directly into atomic motion, which causes the food to heat up.

Most microwaves transmit across the 2.4-GHz ISM band while heating food, causing interference to devices using the 2.4-GHz ISM band for communication. Figure 16 shows a signal generated by a 1000 watt microwave oven (Samsung MW5592W). Older microwaves that are not shielded well and high power microwaves produce even stronger signals in the 2.4-GHz ISM band.

Figure 16. Microwave Oven (500 ms Capture)



Microwave and WirelessUSB LP/LPstar Interaction

Most commercial microwaves transmit a strong, but sporadic signals across the upper half of the 2.4-GHz ISM band. This can cause WirelessUSB LP/LPstar to change channels to a channel in the bottom half of the 2.4-GHz ISM band. Industrial strength microwaves may transmit a strong signal across the entire 2.4-GHz ISM band, causing noticeable interference at short distances (within 2 meters).

Multiple System Interactions

Wi-Fi

Wi-Fi and Bluetooth

Configuration Details

Tests were also performed with multiple 2.4-GHz ISM systems in the following configurations:

- Two Wi-Fi access points on separate channels, located 10 meters from the WirelessUSB LP/LPstar Bridge.
- One Bluetooth device located 10 meters from the WirelessUSB LP/LPstar Bridge.
- One WirelessUSB LP/LPstar Mouse located 10 meters from the WirelessUSB LP/LPstar Bridge.
- One Wi-Fi endpoint located 10 meters from the WirelessUSB LP/LPstar Bridge.
- One Bluetooth device and one Wi-Fi endpoint located 0.25 meters from the WirelessUSB LP/LPstar Bridge (to simulate a laptop with Wi-Fi, Bluetooth, and WirelessUSB LP/LPstar).
- One WirelessUSB LP/LPstar Mouse located 10 meters from the WirelessUSB LP/LPstar Bridge.

Pass Criteria

All tests passed with the following criteria:

- No perceived latency on WirelessUSB LP/LPstar Mouse.
- Less than 1% loss of data throughput on Wi-Fi networks.
- Less than 1% loss of data throughput on Bluetooth networks.
- No perceived loss of voice quality on DSSS Cordless Phone.
- No perceived loss of voice quality on FHSS Cordless Phone.

Other Multiple Systems

FHSS Cordless Phones and DSSS Cordless Phones

Configuration Details

Tests were also performed with multiple 2.4-GHz ISM systems in the following configurations:

- One DSSS Cordless Phone located 10 meters from the WirelessUSB LP/LPstar Bridge.
- Two FHSS Cordless Phones in intercom mode located 5 meters from the WirelessUSB LP/LPstar Bridge.
- Two FHSS Cordless Phones in intercom mode and two DSSS Cordless Phones in intercom mode located 10 meters from the WirelessUSB LP/LPstar Bridge.
- One WirelessUSB LP/LPstar Mouse located 10 meters from the WirelessUSB LP/LPstar Bridge.

Pass Criteria

All tests passed with the following criteria:

- No perceived latency on WirelessUSB LP/LPstar Mouse.
- Less than 1% loss of data throughput on Wi-Fi networks.
- Less than 1% loss of data throughput on Bluetooth networks.
- No perceived loss of voice quality on DSSS Cordless Phone.
- No perceived loss of voice quality on FHSS Cordless Phone.

Wi-Fi, FHSS Cordless Phones, and DSSS Cordless Phones

Configuration Details

Tests were also performed with multiple 2.4-GHz ISM systems in the following configurations:

- Three Wi-Fi access points on separate channels, located 10 meters from the WirelessUSB LP/LPstar Bridge.
- Two Wi-Fi endpoints located 10 meters from the WirelessUSB LP/LPstar Bridge.
- One Wi-Fi endpoint located within 0.25 meters of the WirelessUSB LP/LPstar Bridge (to simulate a laptop with both 802.11 and WirelessUSB LP/LPstar).
- One DSSS Cordless Phone located 1 meter from the WirelessUSB LP/LPstar Bridge (to simulate an office

containing a DSSS Cordless Phone and a computer with WirelessUSB LP/LPstar).

- Two FHSS Cordless Phones located 5 meters from the WirelessUSB LP/LPstar Bridge.
- One WirelessUSB LP/LPstar Mouse located 10 meters from the WirelessUSB LP/LPstar Bridge.

Pass Criteria

All tests passed with the following criteria:

- No perceived latency on WirelessUSB LP/LPstar Mouse.
- Less than 1% loss of data throughput on Wi-Fi networks.
- Less than 1% loss of data throughput on Bluetooth networks.
- No perceived loss of voice quality on DSSS Cordless Phone.
- No perceived loss of voice quality on FHSS Cordless Phone.

Summary

All standard 2.4-GHz networking technologies have made design tradeoffs to mitigate the effects of or avoid interference. Designers can create systems that are frequency agile either by using the procedures provided by the standard being implemented or by building their own protocol using the methods mentioned here in conjunction with radio features such as RSSI when available.

While it is not possible to completely eliminate interference from outside 2.4-GHz systems, designers can create systems that are frequency agile thereby giving their product the best chance to survive in today's competitive 2.4-GHz ISM band environment.

WirelessUSB LP/LPstar is designed to coexist with all other 2.4-GHz technologies. DSSS, strong error correction, retransmission, and frequency agility make WirelessUSB LP/LPstar robust to interference from other technologies. This allows WirelessUSB LP/LPstar to work reliably at 10 meters in the typical wireless office. Further, WirelessUSB LP/LPstar does not cause excessive interference to other 2.4-GHz technologies.

Document History

Document Title: AN4004 - Interference Mitigation Challenges and Solutions in the 2.4 to 2.5-GHz ISM Band

Document Number: 001-15255

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	1960706	RKV	06/16/2008	Changed app note title from "WIRELESSUSB(TM) LS INTERFERENCE AVOIDANCE - AN4004" to "Interference Mitigation Challenges and Solutions in the 2.4 to 2.5 GHz ISM Band - AN4004". Updated app note content.
*A	3147642	NXZ	01/19/2011	Removed redundant figure. Removed obsolete AN references.
*B	3223578	KKCN	06/24/2011	Updated the text with LPstar features.
*C	4428175	LIP	07/02/2014	Updated in new template. Completing Sunset Review.
*D	5798874	CHYY	06/29/2017	Updated in new template.

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