

Resilience to Interference

Interference in the 2.4GHz band

The ISM (Industrial, Scientific, and Medical) bands, established by treaty at the International Telecommunications Union (ITU), are allocated for use in most countries in the world in a number of bands including 2.4 to 2.483GHz. As the band name implies, devices operating in these bands range from Industrial devices that treat food, chemicals, packaging, textiles and construction materials; Scientific applications such as microwave lamps or heaters and Medical devices which can heat body tissues, provide magnetic resonance imaging, or even provide radiometry for cancer detection. Another important source of ISM interference comes from the domestic arena in the form of commercial microwave ovens, of which there are millions in use around the world.

In addition to ISM devices, interference can also be experienced by Military radar, radio-location and Amateur radio, depending on the country where these systems are deployed.

Communication Systems such as Wireless LANs (WLAN), Bluetooth handsets or PDAs, Cordless Telephones (in the US) and even analogue CCTV transmitters can all operate within the 2.4GHz band. The ability for a communications system to operate in the presence of these unwanted emissions is thus a key requirement of any professional system utilising the 2.4 GHz band. It is for this reason most communications systems utilise some kind of spread spectrum technology due to its inherent resilience to interference.

Spread Spectrum Modulation

Spread spectrum techniques originally developed for military applications and are now commonly used in sophisticated digital transmission systems. By definition, a spread-spectrum system expands, or spreads, the bandwidth of the signal. There are two fundamental techniques for spectrum spreading: direct sequence and frequency hopping, each have different physical mechanisms for rejecting interference.

Direct-Sequence Spread Spectrum (DSSS) combines the information signal with a spreading signal having much wider bandwidth, see Figure 1. The net modulation signal effectively handles the wide bandwidth of the spreading signal. This wide modulation is then applied to a single fixed frequency carrier signal for transmission.

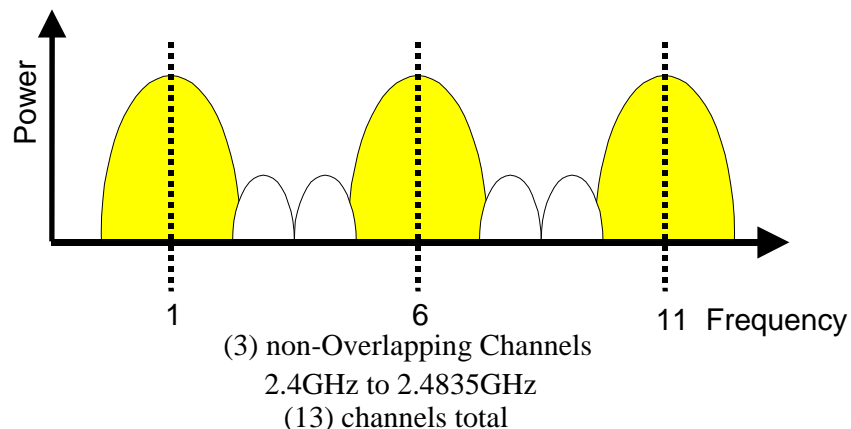


Figure 1: Direct Sequence – Spreading the signal over frequency

Frequency Hopping Spread Spectrum (FHSS) takes the opposite approach. Rather than spreading the modulation about a fixed carrier, the information is left unchanged and directly modulates a carrier of varying frequency, see Figure 2. In frequency hopping, the spreading signal is used to change the frequency

of the carrier provided by the carrier generator. The data directly is modulated on this hopping carrier, in essence the frequency hopping approach is just a collection of conventional narrow-band signals.

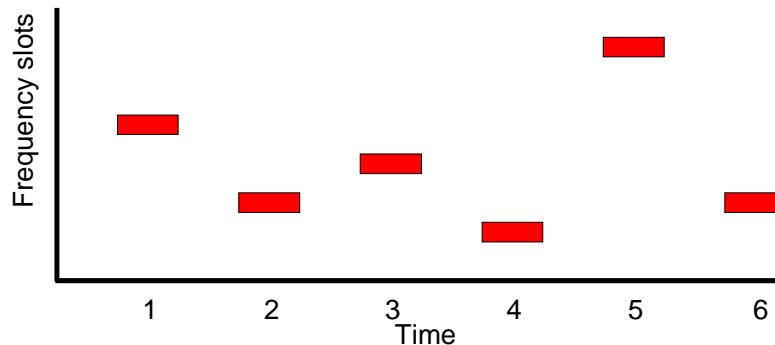


Figure 2: Frequency Hopping – Utilising multiple frequency slots over time

Resilience to Interference Signals

Interference to the intended communication occurs only when the following three criteria are met:

1. An interfering signal exists at the demodulation frequency.
2. This interfering signal exists at the time demodulation is attempted.
3. The interference is strong enough to corrupt the demodulation.

A key to the interference rejection of DSSS is the cyclic cancellation of the spreading code under consecutive digital multiplication. This means that a second spreading operation with the same code actually cancels the spreading on input DSSS signals. The spreading process itself is independent of the data, so by cancelling the spreading, the data is left intact. In a real DSSS system, these two stages are employed to process the signals: the transmitter 'spreads' the signal and the receiver 'de-spreads' the signal.

Any interfering signals appear in the channel between the transmitter and the receiver. In the receiver, the multiplier with the spreading code is the second spreading function that the DSSS signal encounters, which cancels the original spreading. However it is the *first* spreading function that the interference "sees." The data is thus recovered as it follows the second stage since the interference signals becomes 'spread' as the data is 'de-spread', see Figure 3.

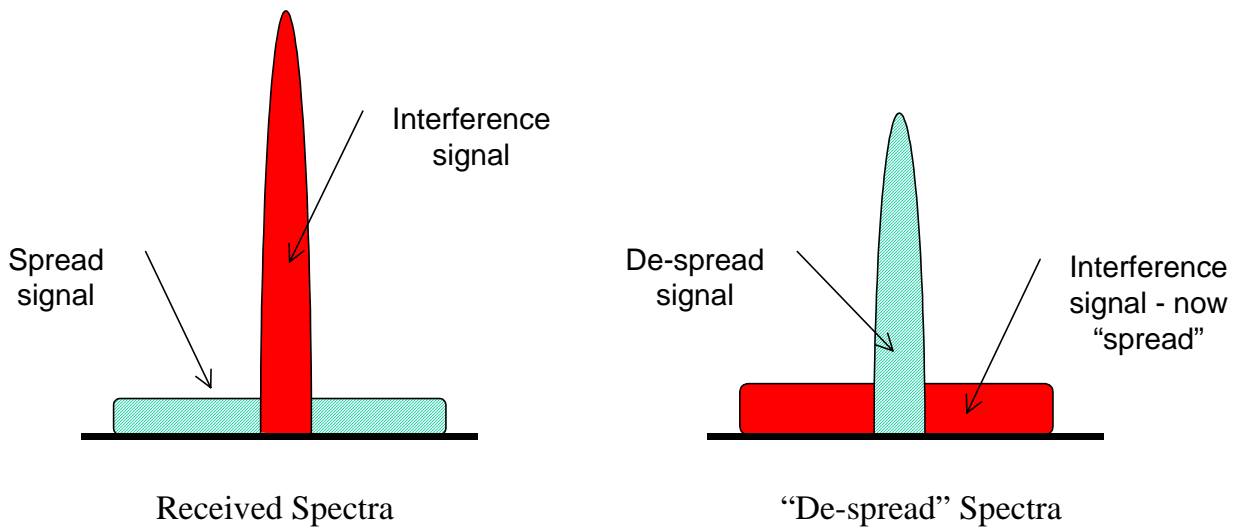


Figure 3 Receiver process spreads interference and de-spreads wanted signal

To actually achieve rejection of the interference, the resulting signal is passed through a band-pass filter. Since the interference signal is spread and thus most of the interference energy is now outside the filter bandwidth (which is designed to pass only de-spread signals) most of the interference energy is blocked from continuing into the receiver. Only a small portion of the interfering signal power remains in the bandwidth of the data signal and this portion appears as a noise floor in the filter pass-band. As long as there is enough signal-to-noise ratio (SNR) in the receiver to successfully demodulate the de-spread data signal, the DSSS system completely rejects the narrow-band interference.

DSSS modulation can therefore tolerate an enormous amount of interference from other devices or signals that it receives within the band, unlike FHSS systems which can be completely jammed on that channel. The approach Hopping Systems take for avoiding interference is simply to try and hop out of the way of interference in order to minimise the overall disruption in signal transmission.

Interference from FHSS Communication systems

As well as coping with spurious interference signals that are received within the band, consideration should also be given to other communication devices that utilise similar technology that also operate within the ISM band. While the spread spectrum and power rules are fairly effective in dealing with multiple users in the band, provided the radios are physically separated, interference can result from radios that are located in close proximity.

The interference problem is characterised by a time and frequency overlap as depicted in Figure 4. In this case a Bluetooth frequency hopping system whose transmissions occupy a multitude of 1 MHz slots can periodically overlap with a Direct Sequence Spread Spectrum signal occupying a 22 MHz channel. Note that, the collision overlap time depends on the frequency hopping pattern and the traffic distribution of both the Bluetooth and DSSS systems. 802.11 FHSS systems follow a deterministic frequency pattern, however Bluetooth FHSS systems specifications define a pseudo-random frequency sequence based on the Bluetooth device address and its internal clock.

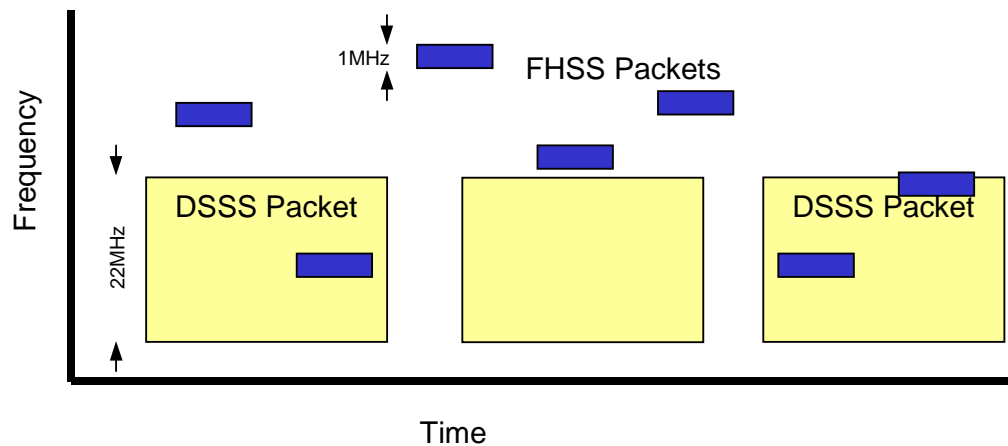


Figure 4: Interference from Frequency Hopping Systems

In addition to the interference rejection inherent with the DSSS processing, the system also has a packet level protection system. All Wavesight radio products data packets are protected with a Cyclic Redundancy Code (CRC) checksum field. If any errors are encountered in reception of the frame/packet, then the CRC detects it and causes the packet to be discarded.

Resilience to Multi-path

When radio systems are deployed in urban areas where buildings and other large objects can reflect signals, receivers can often be presented with more than one signal: the original intended signal and one or more of the reflected signals. However since radio takes a finite time to travel a certain distance, signals that are received directly arrive quicker than signals that have travelled further via reflection. At any one point in time a receiver can thus receive both current direct signals AND previously sent reflected signals. The combination of signals from different time periods means that the resulting signal can be distorted, see Figure 5.

Analogue systems suffer severe consequences from multi-path which can be easily witnessed on analogue CCTV systems in the form of picture break-up or 'ghosting'.

However DSSS can communicate well in the presence of multi-path signals. First lets consider the simple channel, the 'delay spread' of the channel is the average time for delays to propagate. When the delay spread exceeds the bit time of the transmission, reflections of the first bit will arrive at the same time as its subsequent bits and lead to Inter-symbol Interference (ISI). Single carrier digital systems can suffer huge ISI which can result in their deployment being limited in built up areas. Some systems use channel equalisation techniques to invert the channel and minimise this effect. However DSSS avoids this problem with the use of de-spreading. When de-spreading the first reflections of a transmission, subsequent reflections do not de-spread so this interference is treated like any other interference and is reduced by the processing gain.

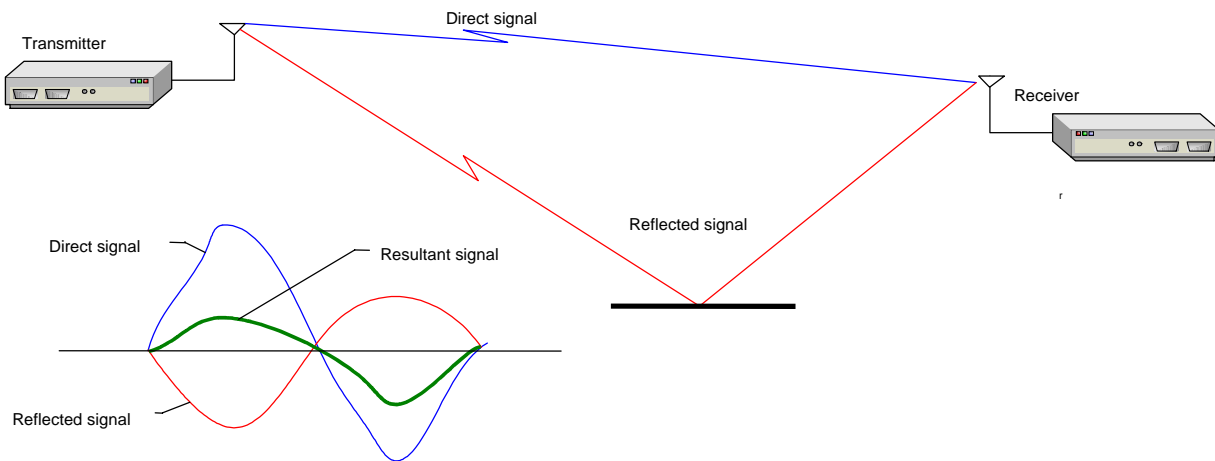


Figure 5: Effects of multi-path on received signals

Resilient Protocol

Wavesight radio products protocol employs both standard HDLC features as well as some proprietary solutions to maximise error detection. The errors that can be detected include:

1. Parity error - when the designated parity condition is not satisfied. It indicates that an incorrect bit (possibly the parity bit) was received.
2. Framing error - if the received input is low in the position of the first stop bit.
3. CRC error - if the correct CRC value is not obtained, indicating that a bit error occurred on the transmission line.
4. Over-run error - if receive data are sent to the receive FIFO when the receive FIFO is full.
5. Under-run error - if the transmit FIFO is empty after transmission of the data in the transmit shift register.

If errors are detected in the packets then as a two way radio communication system, the system can request that the radio packet be resent to the receiver to ensure maximum reliability of the data communications.

Conclusion

Radio interference can be experienced by radio devices either from their own source created by effect like multi-path or from other radio sources that can interfere with the radio transmission. This interference can result not just from devices operating in the band, but also from the harmonics of devices that may operate at a multiple or division of 2.4GHz. It is for this reason that Radio products are tested for spurious transmissions. Wavesight take such product design very seriously and its construction and design has specifically focused on minimising these effects.

This brief paper briefly explains the principles and benefits of DSSS modulation for minimising the effects of interference and multi-path as well as describing some of the error detection algorithms utilised by the Wavesight radio products product. Providing reliable radio links in the unlicensed bands are always a challenge, however it should be noted that Wavesight products employ some of the best resilience to interference techniques available on the market.