Performance of Different Frequency Bands

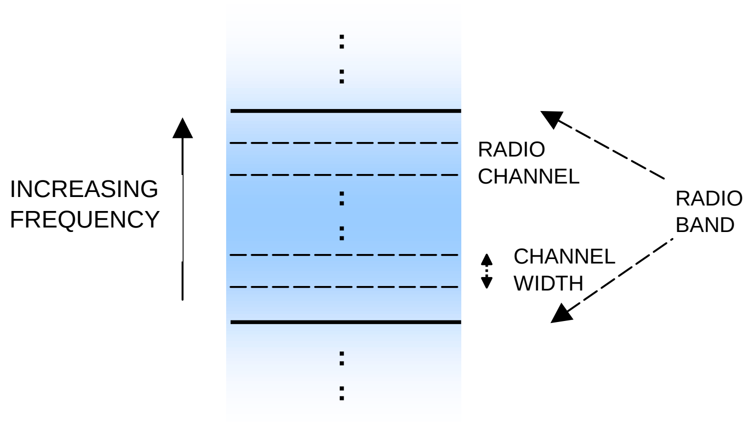
2.4 GHz vs 900/869 MHz

This article looks at the principles of radio technology to explain the differences in performance between different radio bands. It explains the different characteristics in an industrial environment between the common 2.4GHz ISM band and the lesser used 900 and 869 MHz bands

Introduction - an explanation of terms

The use of wireless devices is heavily regulated throughout the world. Each country has a government department responsible for deciding where and how wireless devices can be used, and in what parts of the radio spectrum. Most countries (but not all) have allocated parts of the spectrum for open use, or "license-free" use. Other parts of the spectrum can only be used with permission or "license" for each individual application.

Most wireless products for short-range industrial and commercial applications use the license-free areas of the spectrum, to avoid the delay, cost and hassle of obtaining licenses. The license-free bands are also knows as ISM bands - "Industrial, Scientific & Medical". In many countries there are several ISM bands available, in different parts of the spectrum.



The radio spectrum is split into frequency "bands" and each band is split into frequency "channels". Normally each channel can carry one wireless connection in each geographic area at any one time. Each channel has a regulated width.

The common ISM bands for industrial and commercial applications are:

220 MHz band in China
433 MHz band in Europe and some other countries
869 MHz band in Europe
900 MHz band in North America and some other countries
2.4GHz and 5.7 GHz bands, allowed in most parts of the world.

How Radio Physics affects Operation

The operating frequency and channel-width has a big affect on the performance of a wireless device.

Wider channels allow higher data rates to be transmitted. The channel-widths in each ISM band are regulated and different in the different bands. At higher frequencies, there is relatively more spectrum, so channels are wider. For example, there is 1000 times more spectrum between 1 – 2 GHz as there is between 1 – 2 MHz. Hence the 2.4GHz and 5.7GHz bands have wider channels than the lower frequency bands and can carry much higher data rates than the lower frequency bands. However the increased rate capacity comes at the cost of radio propagation, or radio distance. The higher 2.4GHz and 5.7GHz frequencies have a much shorter reliable distance than the lower frequencies. In most cases, the higher frequency bands will not operate reliably over the distances required for industrial plants and factories.

The reasons for this are numerous. Two fundamental reasons are RF power transmitted and propagation losses. As radio waves pass through the air (or other media), the strength of the radio signal decreases. Eventually the strength will be too weak for the modulated data to be extracted from the radio signal. Radio signals which start with a higher RF power will travel further before the signal becomes too weak.

Also, higher frequency radio waves have a higher propagation loss than lower frequency - that is, the radio signal decreases faster.

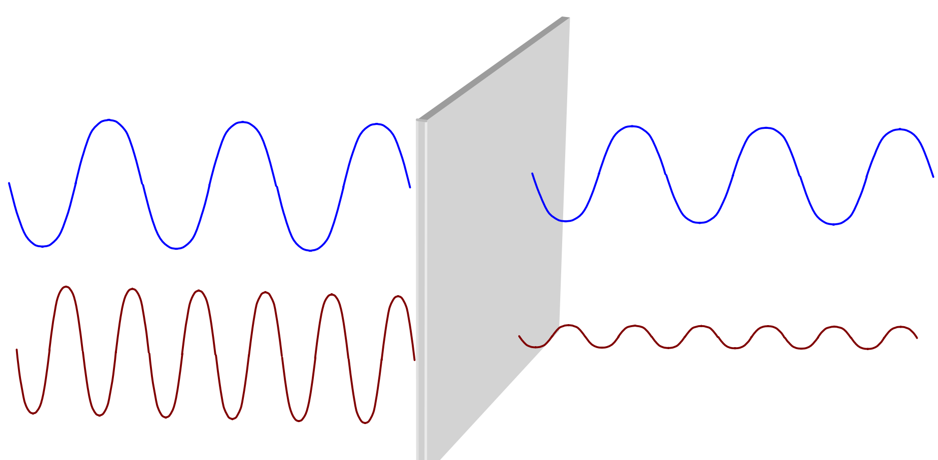
In Europe, 2.4GHz devices are regulated to 100mW of RF power, and the lower 869MHz band allows 500mW power. Without taking into account any other factors, the higher RF power and propagation ability of 869MHz results in reliable distances of five times those of 2.4GHz devices. In North America, the power limit for 2.4GHz and 900MHz devices are the same (1W), however because of the propagation loss of 2.4GHz, the reliable distance through air is only 50%.

In industrial plants and factories, the performance of 2.4GHz vs the lower frequencies is even worse, with reliable distances dropping to 10-20% of the lower frequency bands. In industrial environments there are very few direct ("line-of-sight") radio paths - most paths are obstructed and congested by machinery, steel-work, vessels and buildings. The performance of radio in this type of environment is determined by the ability of the radio signal to:

1. penetrate obstacles, and/or
2. bend around obstacles, and/or
3. reflect from obstacles.

Penetrating Obstacles

Radio waves decrease in amplitude as they pass through walls. As the radio frequency increases, the rate of attenuation increases - that is, the radio strength dies off faster, and the effect of passing through obstacles is much greater.

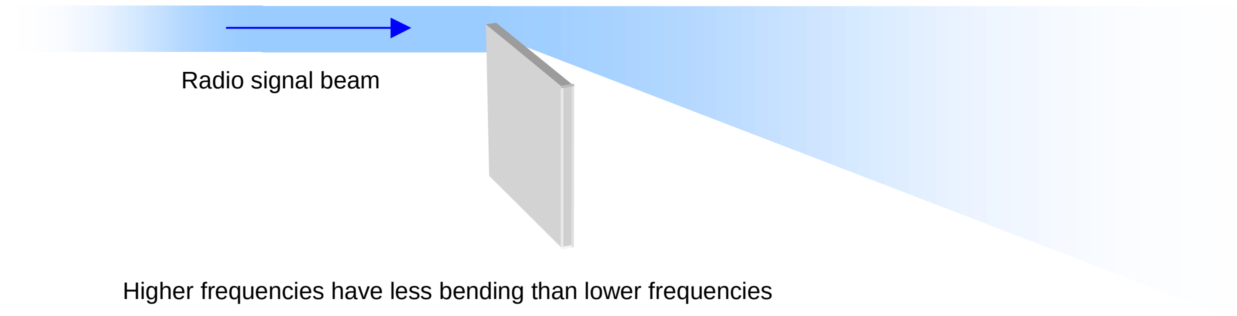


Higher frequencies have higher attenuation on penetrating obstacles

Bending around Obstacles

Radio waves travel in a straight line, however a radio "beam" can diffract or bend when it hits an edge in the same way as light can. The angle of diffraction is higher as frequency decreases - or the ability to bend around obstacles increases as frequency decreases.

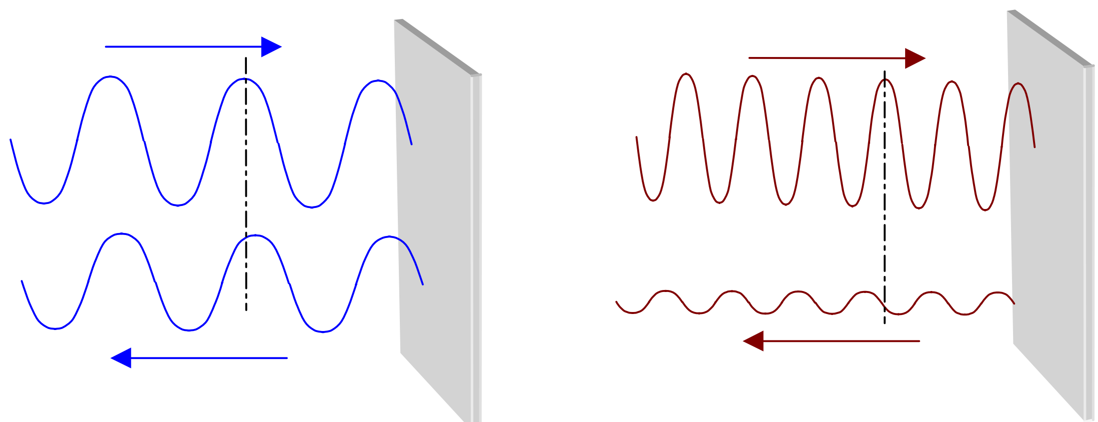
A lower frequency radio signal is “blocked” by an obstacle to a lesser extent as it is able to bend around the obstacle.



Higher frequencies have less bending than lower frequencies

Reflections

Radio waves also reflect from dense surfaces such as metallic walls or vessels. Very often the radio signal has been reflected several times before it reaches the receiver unit. When a radio signal is reflected, some of the RF power is absorbed by the obstacle, reducing, or attenuating, the strength of the reflected signal. This attenuation increases with frequency.



Higher frequencies lose more signal strength on reflection

That is, the reflected signal is weaker for higher frequencies. If the path is very congested, with a lot of consecutive reflections, the 2.4GHz signal fades out quickly.

The End Result

The end result of the effects of RF power, propagation losses, penetration attenuation, defraction and reflection loss is that 2.4GHz has only a very short reliable operating distance in industrial environments - with reliable distances of only around 10-20% of the lower frequency bands. That is, the lower frequency bands reach 5-10 times the distance in plants and factories. In many applications, distances of more than 30 -100 metres (100 - 300 feet) cannot be achieved with 2.4GHz over congested obstructed paths. For typical operating distance in the different ISM bands, refer to the table at the end of this article.

So why is 2.4GHz offered by suppliers?

The advantages of 2.4GHz is high speed and low cost.

The much wider channels at 2.4GHz allow a much higher data rate which cannot be matched by the lower frequencies. For industrial applications over short distance but requiring maximum speed, 2.4GHz is the best choice.

The 2.4GHz band is also used by common commercial wireless technologies such as Wifi, Bluetooth and Zigbee. The ramifications of this is that components for this frequency band are more readily available and hence much lower cost than the other bands. For applications over longer distance but with radio paths which are not obstructed, 2.4GHz may still be a valid choice at a much lower price.

Typical Operating Distances

North America

Line-of-sight paths

2.4GHz, 1W plus 6dB gain antennas	5 – 15 miles
900MHz, 1W plus 6dB gain antennas	15 – 25 miles
2.4GHz, 100mW plus 16dB antennas	10 – 40 miles
900MHz, 100mW plus 16dB antennas	20 – 60 miles

The variation in distance depends on path terrain. Government regulations allow 1W RF power to be generated, and 4W to be radiated (that is, 6dB gain antennas). Greater distance can be achieved with lower power and higher gain antennas - the same amount of RF power is radiated, however the additional gain at the receiver increases the distance, This is only effective in rural areas with low RF noise. In urban and industrial areas, there is no distance advantage.

Heavily congested industrial paths

2.4GHz, 1W	100 – 600 feet
900MHz, 1W	500 – 5000 feet

High gain antennas give little advantage in congested paths because of the large amount of reflected radio signals.

Europe

Line-of-sight paths

2.4GHz, 100mW	1 – 2 km
869MHz, 500mW	4 - 8 km

The variation in distance depends on path terrain. Government regulations allow 100mW RF power for 2.4GHz and 500mW at 869MHz. The 869MHz ISM band is limited to a 10% usage factor.

Heavily congested industrial paths

2.4GHz, 100mW	10 – 100 metres
869MHz, 500mW	100 – 1000 metres