

The Automation Engineer's Guide to Wireless Technology Part 1 - The Physics of Radio, a Tutorial

1 Scope and Purpose

In this technical report, “radio” means “the wireless transmission of information between two or more locations using electromagnetic waves”. The name “radio” (derived from “radiation”) was officially adopted at the 1906 Berlin Radiotelegraph Convention, although the alternative “wireless” remained in parallel use and is now gaining precedence over its competitor. This change in nomenclature is particularly relevant where radio technology is replacing wires. For example the telephone companies’ copper pair subscriber loops are rapidly losing ground to cellular phones, Category 5 (CAT5) cable is giving way to 802.11 wireless local area networks (LANs), and even fiber optic cables can be replaced over short distances by line-of-sight free-space laser links.

The industrial instrumentation and automation field has traditionally relied on wired connections, but the need for greater flexibility and lower costs favors growing applications of wireless technology. In response to this need, the ISA-SP100 Committee was formed to address wireless manufacturing and control systems applications such as the following:

- field sensors used for monitoring, control, alarm, and shutdown;
- wireless real time field-to-business systems (e.g., wireless equipment interfacing work order systems, control LAN, business LAN, voice).

This covers all industries including fluid processing, material processing, and discrete parts manufacturing environments.

Equipment cost will be an important factor. It is easy to imagine new and useful monitor and control applications which, although not feasible today because of the cost of the wired connections, will become practical when the cost of wireless networks has been reduced sufficiently.

The broad scope of these applications suggests that there is unlikely to be an optimum “one size fits all” wireless solution. The bandwidth, throughput, signal latency (transmission delay), bit error ratio, availability and reliability requirements of a wireless local area network carrying large volumes of file transfer or voice traffic or a link used for real-time control of critical temperature or pressure parameters in a process tank are very different from those of a link used to monitor the water level in a remote reservoir, where only a few bytes may need to be transmitted three or four times a day. This technical report focuses on radios using the unlicensed industrial, scientific and medical (ISM) and Unlicensed National Information Infrastructure (UNII) bands. In this technical report where there are references to the ISM bands the UNII bands should also be considered to be included.

These bands have certain aspects in common:

- They are required to comply with regulations set by government agencies, such as the Federal Communications Commission (FCC) in the United States. For example, both transmitter output power and radiated power density are capped, to limit the potential for interference. In general, the regulations are very flexible and provide ample scope for developing innovative solutions to wireless communications problems.
- They are exposed to the constant threat of radio frequency interference from other equipment operating in the same bands.

This technical report presents a general tutorial on the basic principles of radio communications, and then discusses the performance of spread spectrum radio systems in the presence of interference from other ISM band users and non-ideal propagation conditions, such as may be expected in the industrial plant environment. Its objective is to give readers a realistic understanding of how radio links can complement and/or replace wired connections, the factors influencing link range, and the pitfalls for the unwary. Industrial applications for wireless communications range from the relatively non-critical, such as asset monitoring to support preventive maintenance programs, all the way to the highly-critical, involving plant, personnel and public safety. The technical report will show that well-designed radio systems can satisfy these varying needs, but that the associated tradeoffs of performance vs. security and reliability result in different system solutions for different applications.

In general, the radio links analyzed in the technical report are assumed to operate in the ISM bands, and to carry information in the form of digital bit streams. Discussions are limited to the physical layer and error-control portions of the data-link layer of the seven layer open systems interconnection (OSI) model. Wireless networking concepts are touched on only superficially, in the context of spectrum sharing and spectrum management; further details may be incorporated in a future publication. Where examples are given, they are based on the 2.4 GHz ISM band and the rules in effect in North America.

Section 2 of the technical report deals first with the performance of a single, one-way radio link in ideal “free space” conditions, assuming unobstructed line-of-sight propagation of the carrier waves and no sources of interference (such as other transmitters, electrical machinery or electronic equipment), the only sources of impairment being the thermal noise generated in the receiver and the reduction in signal strength due to path losses.

Section 3 of the technical report covers various aspects of radio wave propagation, including reductions in signal strength due to increasing distance from the transmitter and transmission through “lossy” (partially-conducting) media, reflection of electromagnetic waves at conducting, non-conducting or partially-conducting surfaces, multipath signal fading caused by reflections and techniques for mitigating these effects, and the design, selection and deployment of antennas.

Section 4 of the technical report deals with the “real world” issue of how multiple radio systems can “co-exist” without suffering unacceptable levels of radio frequency interference from other users sharing the same frequency bands. Topics discussed include the traditional regulatory approach to spectrum management, the constraints applicable to the unlicensed frequency bands, sources of interference and the effects of interference on radio performance, and techniques to mitigate the effects of interference.

The final section of the technical report addresses the issue of wireless communication standards and how they might be rationalized to facilitate the secure and reliable deployment of radio links in the industrial environment for applications in all categories from non-critical to highly critical.

2 Free space communications basics

2.1 Elements of a radio link

Radio (or wireless) links make use of electromagnetic radiation covering a band of frequencies made up of channels. The width of a channel used is determined by the amount of information to be transmitted in a given time and the modulation and filtering design of the radio. A higher data rate generally requires a wider channel when using a particular modulation format. Modulation is the method by which the data is impressed onto the radio signal. Modulation techniques which impress more data onto a given band are generally more complicated to implement and less immune to propagation impairments and interference. Regulations set the acceptable channel widths and in some cases even the modulation types that may be used in a given band. Narrow band radios normally stay on a single center frequency and occupy only the bandwidth required to accommodate