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I Abstract

RFID readers operating at UHF frequencies (around 900 MHz) are coming into increasing use in a variety of applications. Many of these applications fall into one of three categories: portal, conveyor, or handheld configurations. The readers employ either external or built-in antennas to communicate with the tags. These antennas must be selected and configured to satisfy the specific requirements of each application category. In this article we introduce some fundamental antenna characteristics and then review the application requirements. Future articles will cover the process of finding the appropriate antenna parameters for each requirement.

II. Introduction

Antennas are the means by which the voltages generated by the RFID reader are converted into electromagnetic waves to communicate with the tags, and the scattered waves from the tags are converted back into voltages. The characteristics of the reader antenna, combined with the method of installation and use, often determine whether an RFID tag can be read successfully. As the hardware cost of readers decreases the relative contribution of the cost of site evaluation and installation has become a more significant part of the total installation cost. Careful selection and placement of antennas is a critical consideration for successful low cost deployment.

RFID frequencies differ greatly, and antenna considerations are also distinct for the differing frequency bands. For LF (125 KHz) and HF (13.56 MHz) systems, the wavelength is very long compared to practical antenna sizes, and the antennas are typically coils depending on local magnetic coupling to the reader. These antennas do not radiate significant electromagnetic waves. UHF reader antennas radiate electromagnetic waves that can travel long distances. UHF (typically 860-960 MHz) waves have wavelengths of around 33 cm. UHF antennas can have significant directivity (ability to direct the radiated waves), and thus the region in which a tag can be read – the ***read zone*** – depends on the reader antenna. The exact frequency bands used in RFID differ from one country to another; for example, in Europe[1] 865-868 MHz is generally available, whereas in the United States[2] RFID systems usually operate in the unlicensed ISM band from 902-928 MHz. Asian countries vary widely in the frequency bands allocated[3]. Some antennas can cover all these frequencies, but most are designed for

[1]European standards European Radiocommunications Office, ERO and European Telecommunications Standards Institute, ETSI. http://www.etsi.org/services_products/freestandard/home.htm
[2] United States governmental agency is the Federal Communications Commission, FCC. Part 15 compliant readers section 15.247 for UHF operation. http://www.fcc.gov/oet/info/rules.
[3] Japan: Ministry of Public Management, Home Affairs, Posts and Telecommunications, MPHPT, www.soumu.go.jp/joho_tsusin/eng/laws.html; see also ARIB, www.arib.or.jp/english/index.html. China: Standardization Administration of China, SAC. See also National Radio Spectrum Management Center, www.srrc.gov.cn/ (in Chinese)

narrower bands, and may only be appropriate for some jurisdictions. Antennas used outside their optimal frequency range may reflect much of the power sent to them by the reader, often causing a degraded read range and disappointing performance. Obstacles close to the antenna can also degrade range. Thus, the choice and mounting configuration of reader antennas is important in getting good performance from an RFID reader.

There are other factors that may or may not need to be considered when selecting antennas and readers. The environmental ratings of NEMA or IPC standards determine if the antenna can be located in controlled indoor or more harsh outdoor environments. Even how an antenna looks must often be considered. Is a stealth installation needed? Do you want the antennas to appear more conspicuous for deterrence reasons? Antennas can come with or without radomes and be made to look like other "non-antenna" objects.

Specialized microwave connectors are normally employed to mate the coaxial cable carrying the signals to the antenna and reader. Various connector types are available and the choices specified by radio and antenna manufacturers may not always be the same. The user must pay attention to the connector type and correctly specify it, or provide appropriate adaptors.

III. Fundamental Antenna Characteristics

Input Impedance and Bandwidth

External antennas are generally connected to the reader using flexible coaxial cables and connectors designed for radio frequencies (RF). If the antenna and the cable have the same electrical impedance (typically 50 ohms), power will pass from the cable to the antenna and be radiated as desired. If the antenna impedance differs greatly from that of the cable, the power will instead be reflected back to the reader. The electrical impedance presented by an antenna is a complex function of the frequency, the antenna shape, and the near-antenna environment. Antennas are typically designed to provide a good match to the impedance of the cable in their specified frequency range, when properly mounted and connected.

Antennas can only provide a good match to the cable over a limited frequency range, usually given in the manufacturer's data sheet. (The bandwidth reported there is typically the range over which the antenna will radiate >90% of the power sent to it on the cable.) Antennas used outside their rated bandwidth will reflect much of the power sent to them back to the transmitter; in the extreme case this could damage the reader transmitter, though commercial readers normally have protection circuits that shut down the transmitter when excessive reflection is detected.

The antenna impedance and bandwidth might change as objects are held or mounted directly in the radiation path up to one meter away from the antenna (about 3 times the wavelength). Objects that will strongly affect antenna operation are typically metallic, or contain water or other aqueous liquids. Common plastics and non-aqueous fluids, such as mineral oils, have much smaller effects on RF propagation. The antenna interaction with the parasitic objects can become so large that only negligible power is radiated, and read range will be degraded.

Polarization

Electromagnetic radiation consists of a travelling electric and magnetic field. The electric field has a direction at any point in space, normally perpendicular to the direction of the wave; this direction is the *polarization* of the wave. For linearly polarized radiation, the direction of the electric field is constant as the wave propagates in space. Configurations can also be constructed in which the direction of the electric field rotates in the plane perpendicular to the direction of propagation as the wave propagates; this is known as *circular polarization.* (See Figure 1.)

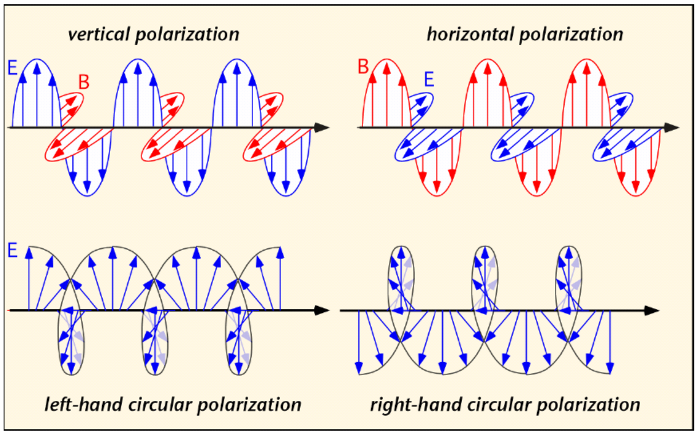

Figure 1: Linear and circular polarizations of traveling electromagnetic waves

The best power transfer between antennas is obtained when their polarizations match. Thus the best read range is obtained from e.g. a vertically polarized reader antenna transmitting to a vertically polarized tag antenna. This is an excellent scheme to employ when the orientation of the tag can be controlled. However, if the orientation of the tag can vary, the tag could accidentally be perpendicular to the polarization of the reader antenna. (See Figure 2.) Very little power is received with a horizontal tag and a vertically polarized transmit signal; the tag will not be read. When the tag orientation is unknown or uncontrollable, a circularly polarized antenna should be used. Vertical tags, horizontal tags, and tags rotated to intermediate angles can then be read with equal facility. However, this versatility is not without cost. A circularly polarized signal can be regarded as the combination of a horizontal and vertical signal, each containing half of the transmitted power. A linearly polarized tag antenna only receives its own polarization, and thus half the transmitted power. The read range of a circularly polarized antenna with a linearly polarized tag is reduced from what could be obtained with a linearly polarized reader antenna, if the tag orientation is known.

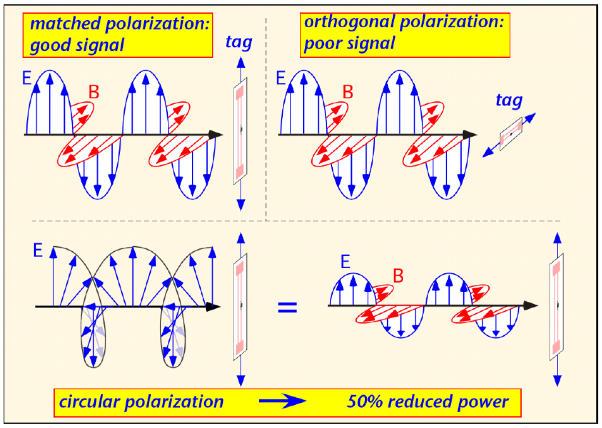

Figure 2: Orientation of the tag compared to the reader antenna's polarization

Gain and Effective Radiated Power

When the reader transmits, it sends RF-power through the cable to the antenna. A real world antenna does not radiate isotropically: instead, power is focused in certain directions in preference to others. Because this has the same effect as increasing the input power (at least for those observers located where the maximum power is directed), the ability of an antenna to radiate preferentially in a certain direction is often known as its ***gain***.

Radiation patterns – pictures of the amount of radiation in each possible direction -- vary tremendously for different antenna designs. (See Figure 3.) Typically the direction of maximum radiation is defined in the antenna datasheet and is visible in a radiation pattern plot. Gain is often reported in 'dBi', the 'i' denoting the use of an ideal isotropic antenna as reference[4]. Because an ideal isotropic radiator does not exist, antenna manufacturers sometimes specify 'dBd', the 'd' denoting the use of a standard half-wavelength dipole as a reference, which itself has a 2.2 dBi gain over an ideal isotropic radiator. For example a quarter wave monopole over a ground plane (Marconi Antenna) has a gain of 3 dBd, which is accordingly 5.2 dBi.

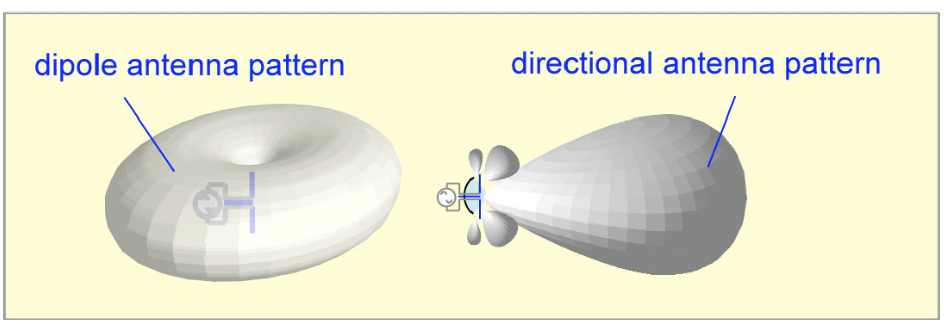

Figure 3: Three-dimensional radiation pattern of a dipole and a more directional antenna.

The ***effective isotropic radiated power*** (EIRP) is commonly defined as the product of input power and antenna gain; it can also be found as the sum of the input power in dBm and the antenna gain in dBi. (Recall the logarithm of a product is the sum of the

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[4] dB = deciBel is a method of logarithmically describing the ratio of two power levels; P_{21} (dB) = log10(P_2/P_1). Thus 10 dB represents a factor of 10 in power.

logarithms: log(a*b) = log(a)+log(b).) The term ERP is also used, sometimes synonymously with EIRP and sometimes referring to the gain referenced to a standard dipole (dBd); unless defined precisely, the term ERP is somewhat ambiguous, and should be avoided.

Circularly polarized antenna gains are specified as ‘dBiC’ and ‘dBdC’, ‘C’ denoting the circular polarization. Here the gains are defined assuming a similarly-polarized receiving antenna; if a linearly-polarized antenna, like a typical single-dipole RFID tag, is used, the power received is half of that from a properly-oriented linearly polarized antenna of the same gain.

Antenna gain directly influences read range and read zone. Higher-gain antennas put more power into the main beam for the same input power, so a tag in the beam will be seen from a larger range. Higher gain also means a narrower beam and narrower read zone. Theoretically, a six dB increase (factor of 4) in effective radiated power will double the read range. However, regulatory limits on EIRP generally prevent the use of high antenna gains with high input powers.

III. Application Categories

Portal

In doorway (*portal*) applications, it is desired to read the tags on items passing through a doorway or gateway. In a warehouse, the portals must be large enough for easy transport of pallets or cages by pallet jacks or forklifts, and are typically around 3 meters in width, and of similar height. The read zone of the RFID system should encompass the whole of the interior of the portal, while excluding regions outside of it, where items or pallets may be staged for shipment or in transit in a warehouse and should not be read. This can be accomplished effectively with multiple antennas with radiation patterns which ensure overlap of their respective read zones.

Conveyor

Boxes or cases removed from a pallet are often transferred and sorted using automated conveyor belts or rollers. A common application of RFID is the identification of boxes as they travel along the conveyor. A reader intended to read tags that run along a conveyer belt may need an antenna placed on the side or top of the conveyer belt. In this case not only the read zone, but also read range needs to be well-controlled, as it is undesirable to read tags on other parts of the belt, in staging areas near the conveyor, or on neighboring conveyors. Because the transfer velocity of the cases can be high, they may only be present in the read zone for a short time. Therefore it is important to have a high read rate in conveyor applications.

Handheld

In handheld reader applications, antennas must be compact and easy to carry and direct. Antennas will generally be mechanically integrated with the reader, as it is inconvenient to carry the reader and antenna separately. The antenna may be integrated with an RFID reader card, or both may be mounted in the same housing and connected by an internal cable. The integrated antenna will be tuned and optimized for that specific handheld device. The user needs to be aware of how to point the antenna and how to match the tag polarization. The antenna requirements are mainly driven by size and weight. The housing material properties, thickness, and shape, as well as nearby hands or metal objects, will significantly alter the antenna performance. Handheld antennas, being compact, cannot achieve the higher gains available for fixed antennas and readers, but offer the benefits of convenience and flexibility.

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In future articles in this series we will discuss the selection and configuration of antennas for each of these application types.

REFERENCES

[1] **MPR Series Multi Protocol RFID Reader User's Manual,** WJ Communications Inc, 2005.

[2] C. Balanis, **Antenna Theory**, Wiley and Sons Inc., New York, 2nd edition 1997.