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I ABSTRACT

UHF RFID readers are often configured to read tags as a pallet or cage passes through a door or portal area. We discuss antenna selection and configuration for portal reading, antenna cabling and connectors, and interference between collocated portals.

II. INTRODUCTION

A portal reader configuration is intended to identify objects with RFID tags (typically UHF-frequency rags because of their longer read range and unique IDs) as they pass through a doorway entering or leaving a facility such as a warehouse or distribution center. The objects are often cases mounted on pallets or within cages, and the pallets or cages themselves. The height of pallets can vary considerably, from less than 1 meter (3 feet) for heavy objects such as alkaline batteries, to 3 meters (10 feet) for large cases with lighter less dense objects such as clothing.

Performance measures for such a configuration are:

- **Percentage of tags read:** the likelihood of reading a tag on an object passing through the portal. This is formally a measure of ***false negatives***: tags that should have been read but were not.
- **Spurious tags read:** the likelihood of reading a tag that is not within the target portal. This is a measure of ***false* positives**: tags read that should not have been. Spurious reads can result when tagged objects are staged for transport too near the portal, when a reflecting object passes close to an antenna and redirects its radiation, or when people walk by carrying tagged objects. More subtle variations of this error are tags passing through one portal and being read in a neighboring portal, causing an error in the presumed location of a tag and thus its inferred origin, present location, or destination.

It may also be important to establish the direction of travel of a tagged object or pallet if the same portal is used for both entering and leaving the facility. Current RFID technology does not allow the RFID reader to unambiguously determine the direction of travel. In individual instances, human judgment suffices, but for high-volume operations additional sensors and other inputs must be considered by middleware to determine the meaning of particular tag reads.

III. ANTENNA SELECTION AND CONFIGURATION FOR PORTALS

In part I of these series we introduced fundamental antenna parameters: impedance match, gain, and polarization, and associated terminology.

In order to minimize spurious tag reads, it is clearly desirable to use directional antennas – antennas with high gain and a well-defined primary beam -- so that we can create a well-defined main read zone. However, regulatory restrictions typically prevent the use of very high gains. For example, in the United States, an antenna connected to a 1-watt reader is limited to a gain of 6 dBi for unlicensed operation.

A very popular antenna for this range of gain is the ***patch*** or ***panel*** antenna (Figure 1). Patch antennas for 900-MHz applications are typically 20-30 cm on a side, and are convenient to mount and adjust. Patch antennas typically have gains around 6-8 dBi, and most of the radiated power is in a well-defined beam around 90 to 100 degrees wide, perpendicular to the front face of the antenna (Figure 2). The antenna can be designed to radiate with a specific polarization. Patch antennas are normally packaged in plastic radomes, with a short length of cable terminating in a specialized microwave connector (to be discussed below).

Figure 1: typical patch antenna

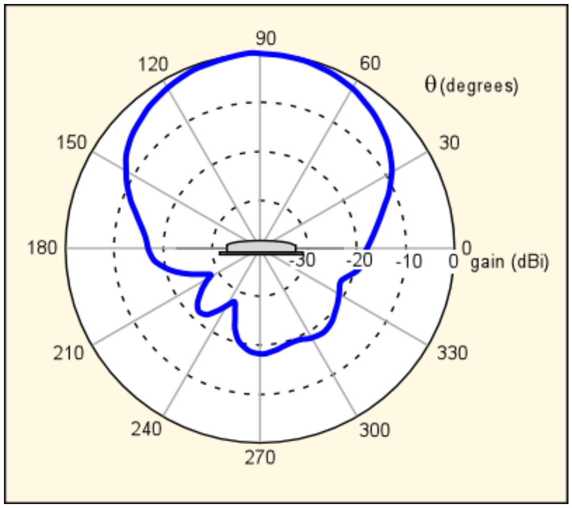


Figure 2: radiation pattern (radiated power density vs. angle) of a patch antenna, oriented as per the thumbnail image in the center.

The main read zone of a patch antenna is a roughly elliptical region projecting from the front surface (Figure 3). In a portal installation, four inward-facing antennas are typically used, with the overlap of the read zones ensuring good coverage of the interior region of the portal and accounting for possible variations in pallet height (Figure 4(a)).

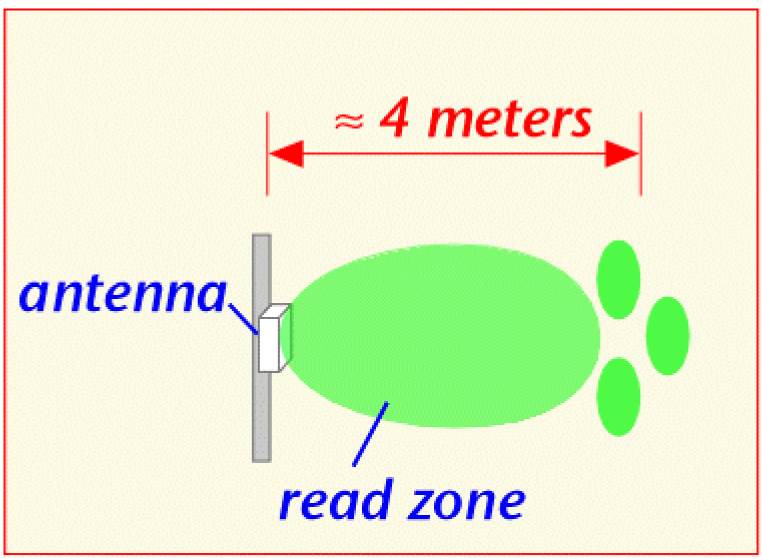


Figure 3: schematic depiction of read zone for a patch antenna. Far from the antenna read behavior is often a complex function of position due to reflection of the transmitted signal from the floor and nearby objects.

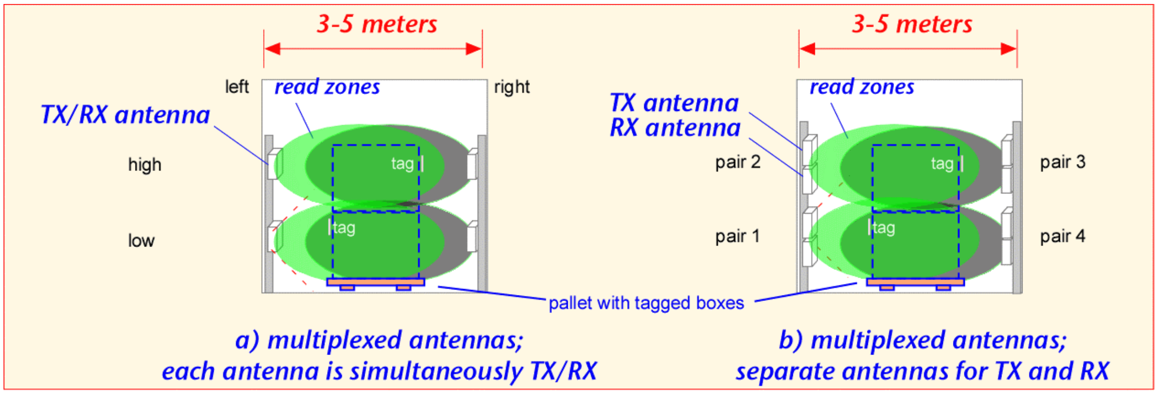


Figure 4: typical portal configurations. a) reader configured to use one antenna for both transmit and receive; b) reader configured to use separate antennas for transmit and receive

It is important to note that these antennas are not all being used simultaneously, but are ***multiplexed*** in time: the reader addresses the antennas in succession to search for tags. A single reader may have multiple antenna connections, or a separate multiplexer box may be employed to multiplex a single transmitter output.

Some readers (notably many Symbol/Matrics designs) are configured to use separate antennas for transmit and receive; thus, to have a configuration with four inward-facing read points as shown in Figure 4(b), as many as 8 separate antenna connections may be required. The antennas may be configured in pairs, in which a transmit and receive antenna are mechanically connected within a single housing, or they may be physically separate patch antennas, in which case 8 antennas may be present in the portal. In this case it is important to appreciate that the antennas are used in pairs, and the corresponding pairs of antennas should be collocated and view the same region. For example, if transmit antenna #1 (the numbering being determined by the reader port to which each antenna is connected) is mounted on the bottom left site, receive antenna #1 should be located close to transmit antenna #1 and parallel to it, so that it views the region illuminated by the transmit antenna. Other configurations, such as transmit and receive antennas mounted on opposite sides of the portal, are likely to degrade read percentage: the large signal from the transmit antenna tends to make the smaller tag reflections difficult to identify.

The width of the read zone is small when objects are close to the antenna. If tags pass very close to the antenna as they travel through the portal, there may only be a short time when a given tag is within the read zone of the appropriate antenna, and if this particular antenna is not being addressed at that time the tag could be missed. Tags at intermediate height traversing the portal near the antennas could also pass between the read zones of the low and high antennas and be missed.

Obstacles placed within the antenna beam and close to the antennas will introduce reflections that make it more difficult for the reader to detect the tag signal. For example, large metallic posts are often placed in front of loading doors to prevent accidental damage to the doorframes by a forklift or its load. If an antenna is positioned behind such a post, reflections from the post will reduce the read range and decrease the percentage of tags read. It is also of importance to prevent obstacles such as metal objects being transported or stored, from blocking the antenna beams. Human beings can also act as obstacles, since they are composed of mostly water and reflect and absorb microwave radiation.

If single-dipole tags are to be used in the portal, it is advisable to employ circularly-polarized antennas. As discussed in part I of this series, a circularly-polarized antenna will successfully detect a single-dipole tag mounted either vertically or horizontally, at the cost of a modest reduction in read range. A linearly polarized antenna will have a very poor read range for ***cross-polarized*** tags (tags that are oriented perpendicular to the antenna polarization). Dual-dipole tags are relatively insensitive to antenna polarization, but are typically a little larger than single-dipole tags.

IV. Cabling and Connectors

Cabling is an important consideration for portal configurations. In most installations, a single reader is connected to all the antennas in a portal. Since the portal is tall and wide, the reader may be located at some distance from the antennas, and cabling needs to be routed away from moving people and equipment, cable lengths of 10-20 meters (30-60 feet) could be encountered between the reader and the most distant antenna. At UHF frequencies, signals can lose power as they propagate along a cable. The loss generally increases for smaller-diameter cables (Figure 5). Cable losses should be less than 2 dB to avoid reducing read range significantly; for a 5-meter length of cable, the cable loss should thus be less than 0.4 dB per meter. From Figure 5, we can see that cables with diameter less than about 0.5 cm are unlikely to be appropriate for such requirements. Use of long cables with high loss, while inexpensive and convenient, may result in greatly reduced read range. Unfortunately, cable nomenclature is historical and bears no simple relation to cable size, loss, or other characteristics as seen below in Table 1 for some common cheaper cables.

Table 1. Approximate cable losses for common 50 ohm cables.

Cable Type	RG58/U	RG59/U	RG8/U	RG174/U	RG188/U	RG213/U
UHF loss dB/m	0.66	0.36	0.30	1.0	0.98	0.31

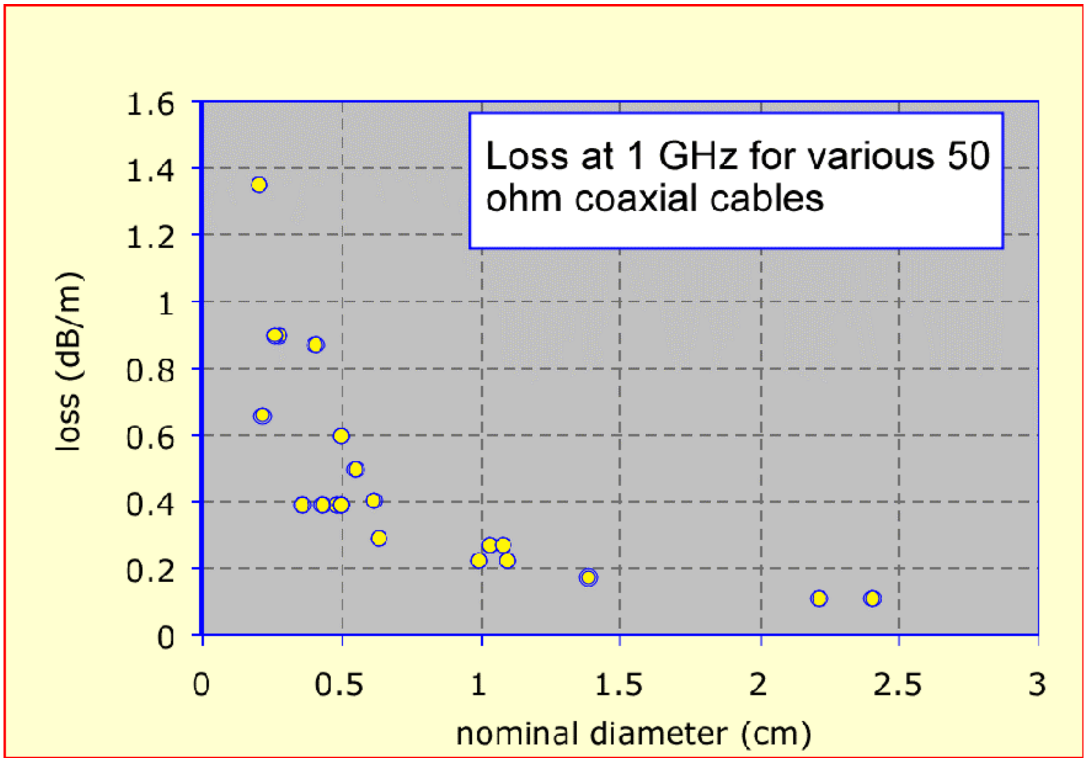
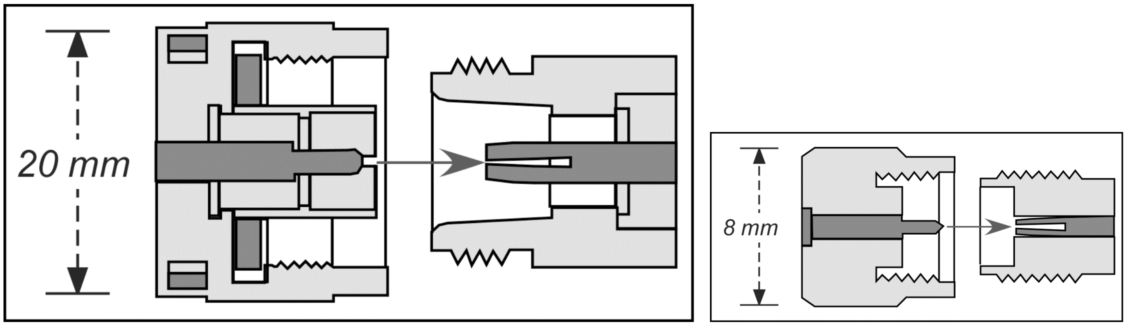


Figure 5: cable loss versus cable diameter

UHF cables use specialized microwave connectors of various types. The most common standard connectors appropriate for use at these frequencies, the type-N connector and SMA connector, are shown schematically in Figure 6. Other less-common types are the Type F, mini-UHF, and TNC. Note that in the United States, the Federal Communications Commission has often required that 'non-standard' connectors be used on some equipment to discourage users from making changes in the antenna configuration that might invalidate the certification of the radio. This requirement has often been satisfied by using gender-reversed connectors (in which the pin, normally associated with the 'male' connector of a pair, is instead located in the 'female' housing); these are often known as ***reverse-polarity*** connectors, not to be confused with antenna polarization. Another means of satisfying such a requirement is the use of connectors with screw threads of the opposite sense from normal: non standard counter-clockwise tightening.



(IV) (b)

Figure 6: common microwave connectors (not to scale): a) type N connector b) SMA connector

V. Interference and Collocation

The reflected signal from a passive tag is small, and easily overpowered by the transmitted signal from a neighboring reader. An example is depicted in Figure 7: a tag even when very close to a reader produces a small backscattered signal (-55 dBm in the case shown, about 3 nanowatts). A separate reader 20 meters away, whose transmitting antenna is directed at the receiving antenna of the other nearby reader, produces a much larger interfering signal (-12 dBm, or about 60 microwatts: about 100,000 times larger than the tag signal!).

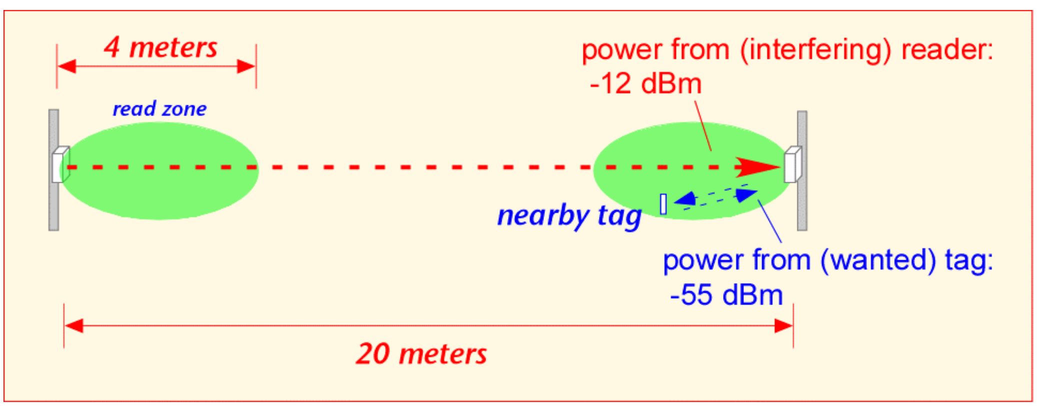


Figure 7: distant reader interferes with nearby tag

The importance of interference depends on the amount of spectrum available for operation and the physical arrangement of the readers. An interfering reader whose operating frequency is several MHz away from the victim reader's channel is much less of a problem, as the interfering signal is filtered out within the radio. In the United States, the ISM band at 902-928 MHz (26 MHz total) is available for unlicensed RFID operation. Readers configured for frequency hopping are required to change channels in a pseudo-random fashion and typically use all the channels with equal probability (Figure 8). This band provides fifty 500-KHz channels for readers to operate in. With so many channels available, the likelihood of an interfering reader being close to the victim reader's channel is small when only a handful of readers are present, though it becomes more important when the number of readers becomes significant compared to the number of channels.

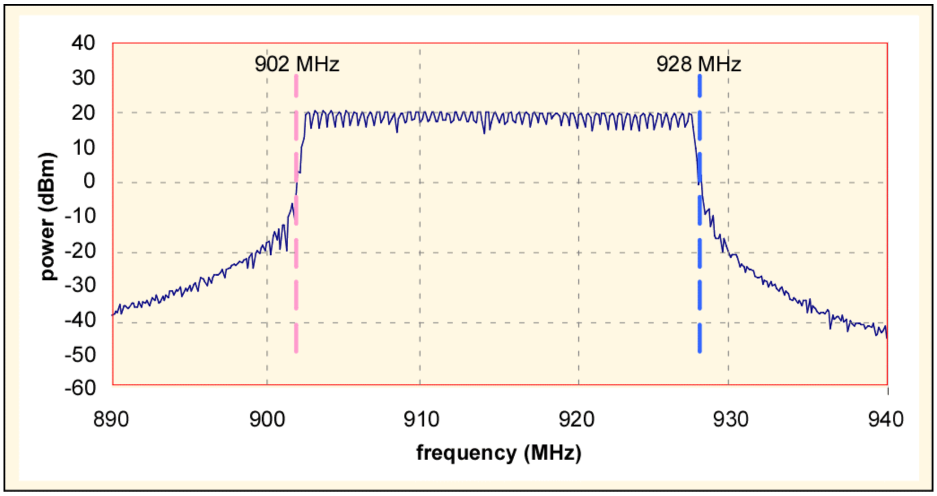


Figure 8: spectrum of frequency-hopping RFID reader configured for US operation

In Europe and Asia, much smaller bands are typically available. For example, Singapore makes a 923-925 MHz range available for unlicensed RFID: there are only 4 channels and the maximum possible channel spacing is 1.5 MHz, so an interfering reader will always be at either the same frequency or close to the frequency of the victim receiver. In Europe, ETSI recommendations allow 3 MHz (865-868), only slightly improving the situation. Thus, interference is potentially an issue even for two or three collocated portals.

One should not optimize the performance of one portal at the cost of degraded performance by its neighbors. The possibility of interference between collocated portals must be accounted for. Several approaches to reducing interference are available. The first and most important is to avoid activating a reader except when there's something to be read. Most portals employ a presence sensor, such as a photoelectric cell or pressure sensitive pad, to detect the arrival of a pallet or cage in the region of the portal and activate the reader. The reader then remains on for a fixed time period while the load of interest passes through the portal. When the percentage of time the reader is on – the ***duty cycle*** – is small, the potential for interference is proportionally reduced. Good procedures can be used to minimize spurious activation by personnel or empty transport equipment crossing the sensor threshold. Multiple sensors can help determine the direction of travel of material through the portal.

Antenna configuration can be used to reduce interference. In some cases it may be possible to redirect antennas outwards, towards the loading dock or other facility access. Such provisions will generally reduce the interfering signal by twice the gain of the antennas (one factor from the transmitter and one from the receiver): in this case, about a 12 dB advantage, or more than a factor of 10 reduction in the interfering signals, is achieved. A similar advantage, at the cost of operational complexity, can be obtained if the multiplexing sequences of differing portals are coordinated, so that at any given moment all antennas either look left or right, and never directly at each other. (Note that in the United States it is not legal to coordinate the frequency channels of distinct readers, though such frequency planning may be allowed or required in other jurisdictions.) Physical shielding can be placed between portals to reduce signal propagation between them. Metal fences or screens can be used for this purpose if the size of the perforations is much less than a quarter of a wavelength: for UHF, the openings should be no larger than 8 cm (3 inches) for significant benefits to be obtained. It is not sufficient merely to block the direct path between antennas; screens should be extended beyond the line of sight in order to reduce ***diffraction*** of the transmitted radiation around the edges of the screen.

The EPCGlobal Class 1 Generation II standard also provides certification of readers for use in multiple-interrogator and dense-interrogator environments, the distinction being based on increasingly stringent requirements for RF radiation outside the intended frequency channel. The standard also provides for operating modes where the tag's reflected signal is located in a slightly different part of the frequency channel from the reader signals, reducing the impact of an interfering signal.

Finally, the reader should note that there are a number of other potential sources of interference in the UHF band, including older wireless local area networks, portable radios, cellphone towers, and broadband sources such as poorly-grounded spark plugs, dimmer switches, and 'bug zappers'. Non-reader interference sources may be sporadic and difficult to detect; a spectrum analyzer and high-gain directional antenna are helpful when otherwise-inexplicable degradations in reader performance are observed.

VI. SUMMARY AND CONCLUSION

To achieve good read percentages and minimize spurious reads in portal configurations, the system should be designed with the following provisions in mind:

- Ensure that antennas are selected and positioned so that their read zones cover the region where tags are to be read;
- Use appropriate cabling and cable routing to minimize RF losses in the cables and avoid mechanical damage;
- Adapt procedures, software, and antenna placement to minimize interference between neighboring readers.