Performance Limitations of Passive UHF RFID Systems

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Abstract

This paper presents an overview of limitations imposed on the range performance of passive UHF RFID systems by such factors as tag characteristics, propagation environment, and RFID reader parameters.

Introduction

Radio frequency identification (RFID) is an automatic wireless data collection technology with a long history [1]. First functional passive UHF RFID systems with a range of several meters appeared in early 1970's. Since then, RFID has experienced a tremendous growth. RFID UHF bands vary in different countries and include frequencies between 860 MHz and 960 MHz (EPCglobal standard).

A passive RFID system operates in the following way. RFID reader transmits a modulated RF signal to the RFID tag consisting of an antenna and an integrated circuit chip. The chip receives power from the antenna and responds by varying its input impedance and thus modulating the backscattered signal. Modulation type often used in RFID is amplitude shift keying (ASK) where the chip impedance switches between two states: one is matched to the antenna (chip collects power in that state) and another one is strongly mismatched.

The most important RFID system performance characteristic is tag range – the maximum distance at which RFID reader can either read or write information to the tag. Tag range is defined with respect to a certain read/write rate (percentage of successful reads/writes) which varies with a distance and depends on RFID reader characteristics and propagation environment. A typical inter-dependence of distance, frequency, and read rate is shown in Figure 1 for an RFID system consisting of a reader and a tag tuned to 900 MHz in a specific environment.

In general, read and write ranges are different due to different amounts of power required by chip for these operations. Ideally, an RFID system has tag read/write range of a 100% up to a certain distance and 0% beyond that.

In this paper, we concentrate on range performance limitations which are defined by a combination of tag characteristics, propagation environment, and reader parameters.

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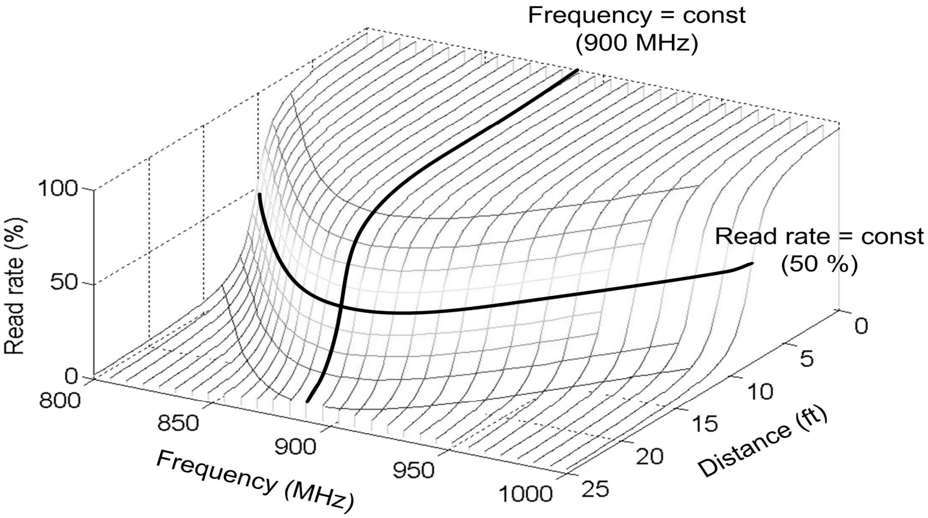

Figure 1 – Read rate vs. distance and frequency in a typical RFID system.

Tag Limitations

Chip sensitivity threshold (P_{th}) is the most important tag limitation. It is the minimum received RF power necessary to turn on RFID chip. The lower it is the longer is the distance at which the tag can be detected. Chip sensitivity is primarily determined by RF front end architecture and fabrication process [2]. RFID chips may also have several RF inputs connected to different antenna ports.

Antenna gain (G_r) is another important limitation. Tag range is highest in the direction of maximum gain which is fundamentally limited by the frequency of operation and the tag size.

Antenna polarization of the tag must be matched to that of the reader antenna for maximizing the range. The match can be characterized by the polarization matching coefficient (χ). Using circular polarized reader antenna with linearly polarized tag removes sensitivity to polarization but incurs additional 3 dB loss.

Impedance match between the antenna and the RFID chip (whose complex impedance varies with the frequency and the power absorbed by the chip) directly affects tag range and can be characterized by the power transmission coefficient (τ) whose maximum value is 1. Impedance can be matched at various chip power levels such as at minimum threshold for maximizing the tag range.

Tag limitations on range can be summarized in the following equation for the power P_{tag} received by the tag:

$$P_{tag} = P_t G_t \, PL \, G_r \chi \tau \geq P_{th} \, , \tag{1}$$

where $P_t G_t$ is reader transmitted EIRP and PL is the propagation path loss.

Propagation Environment Limitations

Path loss strongly depends on propagation environment [3]. For example, in the presence of line-of-sight and multiple single reflections path loss can be written as

$$PL = \left(\frac{\lambda}{4\pi d} \right)^2 \left| 1 + \sum_{n=1}^{N} \Gamma_n \frac{d}{d_n} e^{-jk(d_n - d)} \right|^2 , \qquad (2)$$

where λ is the wavelength, d is the length of the direct ray path, Γ_n is the reflection coefficient of the *n*-th reflecting object (including ground), d_n is the length of the *n*-th reflected ray path, and *N* is the total number of reflections.

In a cluttered environment, the path loss is proportional to d^{-n}, where path loss exponent *n* may vary between 1 and 4 (in free space, *n*=2). In waveguide-like environment where waves propagate only along one direction (pipes, tunnels, etc.) the path loss can behave exponentially with distance due to the modal nature of propagation and may be smaller than in free space until a certain distance from the transmitter where the two become comparable.

Tag detuning is due to the fact that antenna characteristics change when the tag is placed on different objects or when other objects are present in the vicinity of the tag. Tag detuning degrades antenna gain and impedance match and thus affects the tag range.

Reader Limitations

EIRP (equivalent isotropic radiated power) determines the power of the signal transmitted by the reader in the direction of the tag. Maximum allowed EIRP is limited by national regulations (e.g. in North America it is 4 W).

Reader sensitivity is another important parameter which defines the minimum level of the tag signal which the reader can detect and resolve. The sensitivity is usually defined with respect to a certain signal-to-noise ratio or error probability at the receiver.

Factors which can affect reader sensitivity include receiver implementation details, communication protocol specifics, and interference, including signals from other readers and tags. An ideal reader can always detect an RFID tag as long as the tag receives enough power to turn on and backscatter.

The power of the backscattered signal modulated by the tag (ASK modulation) and received by the reader can be calculated as:

$$P_{reader} = P_t G_t^2 (PL)^2 \Delta\sigma \ , \qquad (3)$$

where Δc is the differential radar cross-section of the tag defined by the two modulating states of chip input impedance. For a given chip impedance, RFID tag radar cross-section c can be calculated as shown in [4].

Example

As an example, consider an RFID system where the reader has an EIRP of 4 W (36 dBm) and a sensitivity of -80 dBm. Suppose RFID chip sensitivity is -10 dBm, and chip impedance does not significantly change with absorbed power. Assume further that 2 dBi tag antenna is perfectly matched to the chip at 915 MHz. Figure 3 shows that the range of such RFID system in free space is defined by the limitation imposed by the tag (20 ft), not by the reader (120 ft).

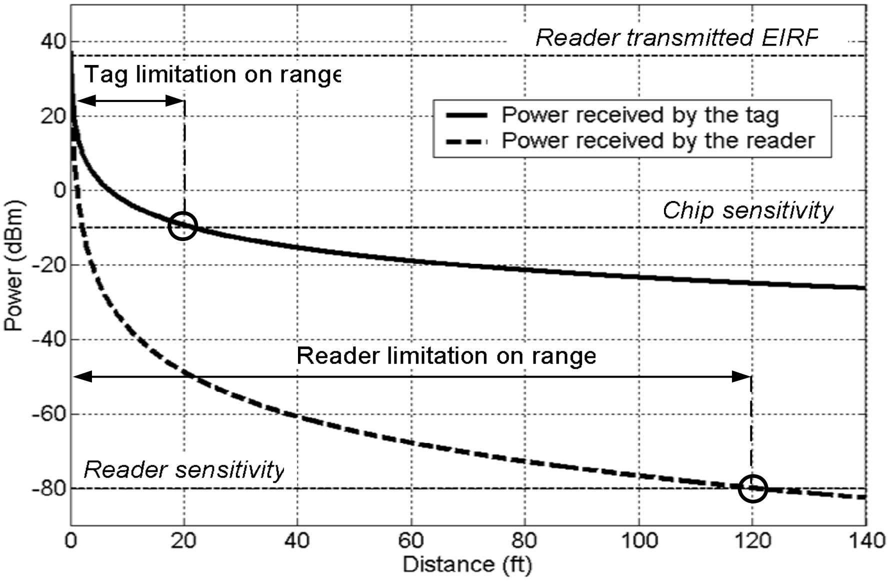

Figure 2 – Received power vs. distance for tag and reader in RFID system.

Conclusions

Range of passive UHF RFID systems is limited by such factors as tag characteristics, propagation environment, and RFID reader parameters. Typically, reader sensitivity is high, and the tag limitation prevails. Tag range can be maximized by designing a high-gain antenna well matched to the chip impedance.

References:

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