Read Range Analysis of Passive RFID Systems for Manufacturing Control Systems

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Abstract: - An RFID system can be considered as a wireless communication system because the reader device communicates with the transponder by using electromagnetic waves at radio frequencies. The performance of this communication link can be studied by determining the read range for backscatter RFID systems. The read range or the distance where the reader unit notices the tag depends on many factors. Frequency used for identification, gain, orientation and polarization of the reader antenna and the transponder antenna, and the placement of the tag on the object to be identified will all have an impact on the RFID system's read range. [1]

This paper presents an approach to analyzing the read range of a backscatter RFID system as a function of frequency, antenna gain and polarization mismatch.

Key-Words: - RFID, Manufacturing Control, Transportation Systems, Production Planning

1 Introduction

In passive RFID systems the energy needed for the communication is entirely from the reader device and it is no good wasting with bad antennas. Two basic principles for data transmission between passive transponder and the reader device are piezoelectric and backscatter or load modulation methods.

In piezoelectric transponders the request signal from the reader device is captured by the tag antenna and converted into surface waves. These surface waves are then reflected back through the converter to the reader device by using the tag antenna. The identification number of the item is coded into these reflected signals that can be detected.

Passive transponders based on backscatter technology use load modulation for communication with the reader. Modulated RF signal is emitted from the reader's antenna; a proportion of which reaches the transponder's antenna. Due to the RF field from the reader antenna a voltage is induced at the input terminals of the transponder. This DC voltage is used to charge a capacitor to provide the bias for the processing circuitry (Figure 1. [3]).

In the return link from a transponder to the reader a proportion of incoming RF signal is backscattered from the transponder's antenna back to the reader antenna. The processing circuit of the transponder changes the RF impedance of the transponder's antenna and controls the amount of this scattered field. In this case the modulation of the scattered field contains the identification information [4]. The transponder is identified when the backscattered field is received and decoded by the reader unit. The role of the antennas is remarkable for this kind of communication system.

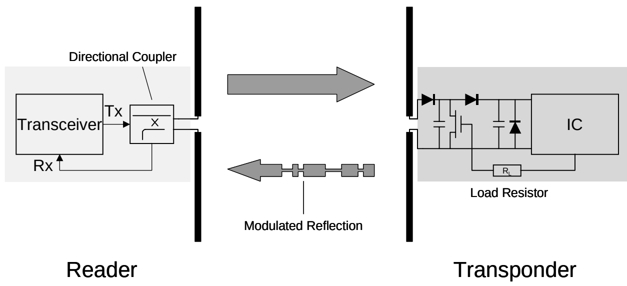

Figure 1. Backscatter RFID system

Characteristics for transponder antennas used in RFID systems are outlined in [5] as follows:

- small enough to be attached to the required object
- have omni directional or hemispherical coverage
- must provide maximum possible signal to the ASIC
- have a polarization such as to match the enquiry signal regardless of the physical orientation of the protected object
- robust
- very cheap

Similarly we can define characteristics for antennas used in RFID reader devices:

- high directivity
- high radiation efficiency
- low side-lobe level to reduce interference
- radiation pattern optimized to the reading zone
- robust
- cheap

There are several types of antennas for microwave range that can be used for RFID. Common antenna types for this frequency range are dipoles (wire, printed, folded), patches, PIFAs (Planar Inverted-F Antenna) and helix antennas. The electrical size of these antenna types is comparable to wavelength of given frequency. Depending on the design used the gain and the radiation pattern varies. The radiation pattern can be omni directional with a peak gain of 0 to 2 dBi or directional where the radiation pattern has a definite lobe and the peak gain might be several dBis [5]. The characteristics of antennas have a radical effect on the read range of RFID systems. In the following paragraphs the effect of antenna properties on read range of the passive RFID systems is studied.

2 Read Range Analysis of Backscatter RFID Systems

Next the read range of backscatter RFID systems is studied. In backscatter RFID systems the reflection of electromagnetic waves from the object is used for the transmission of data from a transponder to a reader [3].

The RF power is propagated in all directions by the antenna of the reader. The power density S at the location of the transponder is

$$S = \frac{P \cdot G_t}{4\pi R^2} \qquad (1)$$

where P is the transmission power of the reader, G_t is the gain of the transmitter antenna and R is the distance between reader and transponder. The transponder reflects a power P_2 that is proportional to the power density S

$$P_2 = \sigma \cdot S \qquad (2)$$

The radar cross section σ is a measure of an object's ability to reflect electromagnetic waves. Depending on the matching of the transponder's antenna σ can vary from 0 to σ_{max} that is the case when the antenna terminals are short circuited of left open. The antenna thus reflects all of the energy arriving at it and acts as a reflecting surface.

$$\sigma_{\max} = \frac{\lambda_0^2}{4\pi} \cdot G_r \qquad (3)$$

The following equation describes the power density S_{BACK} that finally returns back to the antenna of the reader.

$$S_{BACK} = \frac{P \cdot G_t \cdot \sigma}{(4\pi)^2 R^4} = \frac{P \cdot G_t \cdot \lambda_0^2 \cdot G_r}{(4\pi)^3 R^4} \qquad (4)$$

The maximum received power that can be drawn from an antenna, given optimal alignment and correct polarization, is proportional to the power density of an incoming wave. The proportionality factor denoted as the effective area A_e of the antenna is proportional to its gain and is the same as σ_{max} and is defined as

$$A_e = \frac{\lambda_0^2}{4\pi} \cdot G_t \qquad (5)$$

The reception power P_{BACK} of the reader antenna is then

$$P_{BACK} = S_{BACK} \cdot A_e = \frac{P \cdot G_t^2 \cdot \lambda_0^4 \cdot G_r}{(4\pi)^4 R^4} \qquad (6)$$

The equation demonstrates that the read range of such a backscatter RFID system is proportional to the fourth root of the transmission power of the reader. If all the other things being equal we must multiply the transmission power by sixteen to double the range.

The read range R is solved from the equation (6).

$$R = \frac{\lambda_0}{4\pi} \sqrt[4]{\frac{P \cdot G_t^2 \cdot G_r}{P_{BACK}}} \qquad (7)$$

2.1 Effect of Antenna Gain

It is obvious that the antenna gain effects on the read/write range of the RFID system. Next the effect of antenna gain on the read range is studied

The read range for three different transponder antenna types as a function of reader antenna gain is illustrated in Figure 2. The read range is calculated

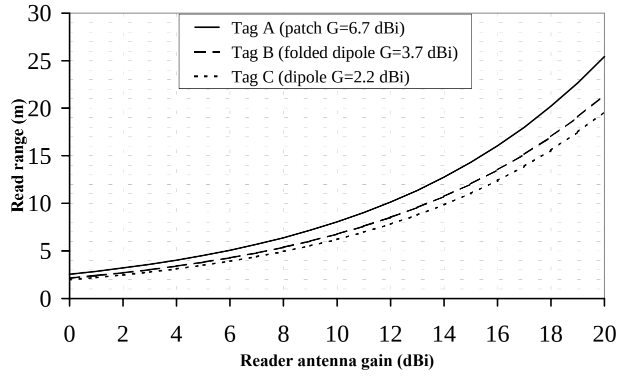

Figure 2. Effect of antenna gain on read range (f = 2.45 GHz)

from the equation (7) for the system in which the sensitivity of the reader P_{BACK} is –70 dBm and the transmitted power P 20 dBm at the frequency 2.45 GHz (λ_0 = 0.122 m). Used values are typical for backscatter RFID systems operating at 2.45 GHz ISM band.

Calculated values in Figure 2. are theoretically maximum read ranges where the reader unit can detect the reflection from the transponder antenna under ideal conditions. Reflections from conductive surfaces, background noise and antenna alignment cut the read range down to at least half of the theoretical maximum when the RFID system is operating in real environment.

2.2 Effect of Frequency

The frequency ranges of operation for common backscatter RFID systems are 915 MHz, 2.45 GHz and 5.8 GHz. Wavelengths for these frequencies are 0.328 m, 0.122 m and 0.051 m correspondingly. In the equation (7) the read range is directly proportional to the wavelength used. By using lower frequency, in other words longer wavelength, the read range can be increased. The read range as a function of reader antenna gain for 915 MHz, 2.45 GHz and 5.8 GHz RFID systems is presented in Figure 3. The transponder antenna used for read range calculations is a folded dipole antenna (G = 3.7 dBi).

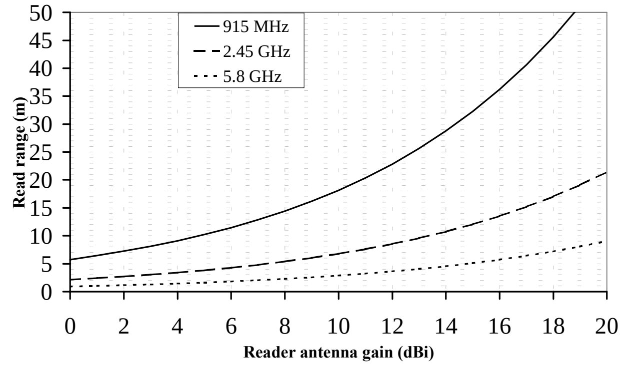

Figure 3. Effect of frequency on read range

In some cases the RF signal from the reader to the transponder has to propagate through an absorbing material. The frequency used has an effect on the propagation losses in the material In Figure 4. the effect of frequency on radio wave attenuation in paper reel is presented.[6] The attenuation between two triple-band antennas was first measured in air and after that through the paper reel so that the transmitting antenna was inside the reel core. The characteristic frequencies of the triple-band antenna used were 450 MHz, 900 MHz and 1900 MHz. As we can see from the Figure 4. the attenuation in the paper reel increases as the frequency rises. The attenuation in the measured paper reel is 8 dB @ 450 MHz, 10 dB @ 900 MHz and 16 dB @ 1900 MHz.

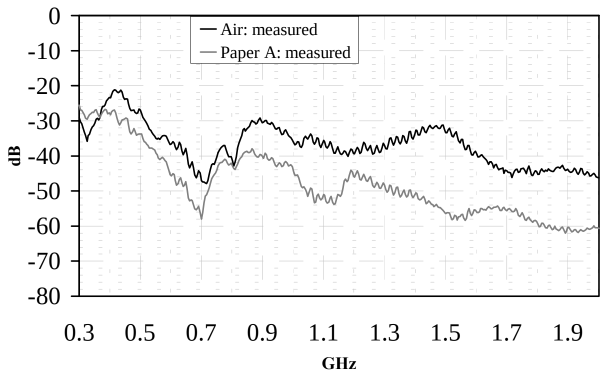

Figure 4. Effect of frequency on radio wave attenuation in paper reel

Because the dimensions of antennas are proportional to the wavelength used, the lower frequency and longer wavelength means inevitably larger transponder size. In most cases the size of an antenna is a limiting factor for miniaturizing transponders in RFID systems. The length of a folded dipole antenna that is commonly used as a transponder antenna is $\lambda_0/2$. This means that the size of a transponder in 915 MHz system is approximately 164 mm while the same type of transponder antenna in 2.45 GHz system fits into 61 mm.

2.3 Effect of Antenna Polarization Mismatch

The case where the polarization of the receiving antenna is not the same as the polarization of the transmitting antenna or the incoming wave can be stated as polarization mismatch. The amount of power extracted by the antenna from the incoming signal will not be maximum because of the polarization loss. [7]

Assuming that the electric field of the incoming wave can be expressed as

$$\mathbf{E}_i = \hat{\boldsymbol{\rho}}_w E_i \tag{8}$$

where $\hat{\boldsymbol{\rho}}_w$ is the unit vector of the wave, and the polarization of the electric field of the receiving antenna can be written as

$$\mathbf{E}_a = \hat{\boldsymbol{\rho}}_a E_a \tag{9}$$

where $\hat{\boldsymbol{\rho}}_a$ is its polarization vector, the polarization loss can then be taken into account by introducing a polarization loss factor. Polarization factor (PLF) is defined as

$$\mathrm{PLF} = \left|\hat{\boldsymbol{\rho}}_w \cdot \hat{\boldsymbol{\rho}}_a\right|^2 = \left|\cos\psi_p\right|^2 \tag{10}$$

where ψ_p is the angle between the unit vector of incident wave and the antenna polarization vector (Fig. 5.).

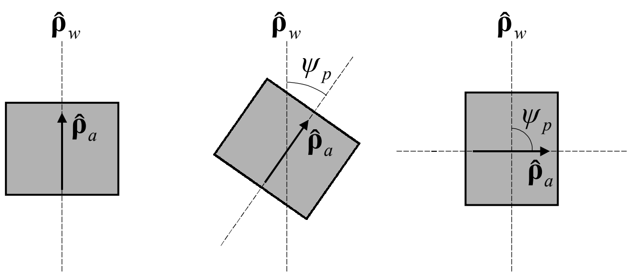

Figure 5. Polarization of antenna and incident wave

The polarization loss factor PLF expressed in decibels

$$\mathrm{PLF(dB)} = 10\log_{10}\mathrm{PLF} \tag{11}$$

is illustrated in Figure 6. for polarization mismatch from 0º to 90º. For antenna misalignments under 45º the power loss is less than 3 dB. If the angle of polarization mismatch increases the power loss starts to increase significantly.

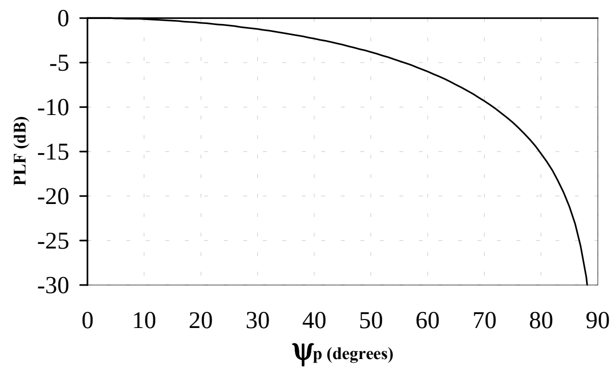

Figure 6. PLF(dB) as a function of polarization mismatch angle

2.4 Using Circular Polarization

Circular polarization can be obtained in an antenna by feeding it with two orthogonal, linear field components having the same magnitude and time phase difference of odd multiples of 90º. [7]

$$E_{x0} = E_{y0} \tag{12}$$

$$\Delta\phi = \phi_y - \phi_x = \begin{cases} +\left(\tfrac{1}{2} + 2n\right)\pi,\ n = 0,1,2,\ldots \\ -\left(\tfrac{1}{2} + 2n\right)\pi,\ n = 0,1,2,\ldots \end{cases} \tag{13}$$

In some cases the use of circularly polarized antennas on RFID reader improves the system performance. In that case the effect of polarization mismatch can be neglected and the angle between the reader antenna and the transponder antenna has no effect on read range. However if the transponder antenna is linearly polarized and the reader antenna is circularly polarized there is a 3 dB power loss irrespective of angle between the antennas compared to the case where the polarization matched linearly polarized antennas on both the reader and the tag are used. This is due to the fact that the circularly polarized field consists of two linear fields having 90º phase shift and the linearly polarized antenna in the transponder notices that part of the field that matches its polarization.

3 Conclusion

In this paper the basic principle of passive RFID system using backscattered waves was presented. In passive RFID systems the energy needed for the communication is entirely from the reader device. Passive RFID systems are easy to apply to a manufacturing and logistics control systems because the transponders are cheap, small and easy to fix to the object to be identified.

The effect of antenna properties on read range and the performance of passive backscatter RFID system was also analyzed. The read range in backscatter RFID systems depends on the transmitted power, the frequency used, the gain of the reader and the tag antennas and the sensitivity of the receiver. The authorities regulate the transmitted power for certain frequency range and it cannot be exceeded. To improve the performance of the RFID system we can concentrate on antennas. By using high gain antennas, antenna arrays or multiple antennas connected to the reader unit the read range can be increased.

The read range is directly proportional to the wavelength used. By using lower frequency, in other words longer wavelength, the read range can be increased. If the transponder is located inside the object to be identified the attenuation of the RF signal can be decreased by using lower frequencies. However, the size of the transponder is in most cases the limiting factor for the antenna structure technically feasible. The size of the transponder also limits the frequency used because the size of the antenna is proportional to the wavelength.

In many applications for manufacturing control the position of the object to be identified on a conveyor is known. In these cases polarization matched linearly polarized antennas can be used to maximize the read range and the RFID system performance. If the position and the angle between the antennas during the identification event are not known there may be losses due to the polarization mismatch. The effect of polarization mismatch can be neglected in these cases by using circularly polarized antennas in the RFID reader. However, if the transponder antenna is linearly polarized and the reader antenna is circularly polarized the maximum read range is in any case less than the read range for polarization matched linearly polarized antennas.

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