工學碩士 學位論文

Design of Tag Antenna and Tag Tracking System Modeling in 3D for Active Radio-frequency Identification System

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Abbreviations

BER	Bit error rate
GBP	Gain-Bandwidth Product
GPS	Global Positioning System
LOS	Light-of-sight
PIFA	Planar Inverted-F Antenna
RFID	Radio-frequency Identification
UHF	Ultra-high Frequency
USN	Ubiquitous Sensor Network

Nomenclatures

ϵ_r	Relative permittivity
ϵ'	Real part of relative permittivity
ϵ''	Image part of relative permittivity
$\tan\delta$	Dielectric tangent loss
μ_r	Relative permeability
μ'	Real part of relative permeability
μ''	Image part of relative permeability
$\tan\delta'$	Magnetic tangent loss
c	Speed of light [m/s]
k	Wave number [m^{-1}]
n	Refractive index (miniaturization factor)
λ	Wavelength [m]
λ_0	Wavelength at resonant frequency [m]
f	Frequency [Hz]
η	Intrinsic impedance of dielectric [Ω]
η_0	Intrinsic impedance of free space [Ω]

요 약

본 논문은 두 부분으로 구성되어 있다: 하나는 새로운 매질을 사용한 RFID 태크용 소형 안테나를 설계하고, 다른 하나는 많은 물체가 고려된 실제 환경에서 동작하는 리더와 태크간의 통신에 적용하기 위한 3차원 태크 추적 알고리즘을 제안한다.

첫 번째, magneto-dielectric 매질을 사용하여 안테나의 크기를 최대한 줄였다. 하지만 안테나의 크기가 작고 매질의 내부 손실 때문에 안테나의 이득이 -4.3 dBi로 낮은 값을 가진다. 이득은 안테나의 크기를 유지시키면서 매질의 유전율과 투자율을 변화시켜 약 -2 dBi로 향상시켰다.

두 번째, 항만 물류 관리 분야에서의 RFID 시스템을 고려하였다. 컨테이너와 같은 물체들은 태크의 인식률을 떨어뜨리게 된다. 따라서 이러한 환경에서 성능에 영향을 끼치는 요소를 찾기 위해 태크의 위치를 추적하는 알고리즘을 제안하였다. 이 알고리즘을 이용한 시뮬레이션 결과는 측정 결과와 일치하는 것을 보였으며, 물체가 있는 RFID 시스템의 분석을 기준의 방법에 비해 보다 쉽고 간단하게 해준다.

Chapter 1. Introduction

1.1 Background

Although radio frequency identification(RFID) technology has been available for more than fifty years, it has only been recently developed at a high speed for several years. It is now the base for many applications such as automated logistics management (even global supply chain, with the support of satellite and global positioning system(GPS)), ubiquitous sensor network(USN), realtime locating system, assets management, etc. Its application increases everyday, and RFID is the hot issue in many places in the world.

Let's review some key points in RFID system. The basic configuration of a stand-alone RFID system is shown in Fig. 1.1.

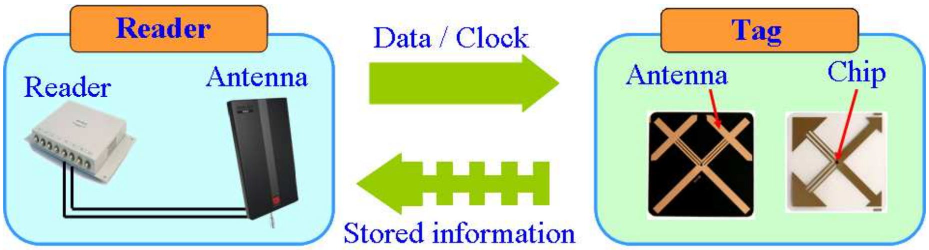


Fig. 1.1 Basic configuration of a stand-alone RFID system

Reader transmits the power, clock, and data to tag by radio wave. The tag receives power and answers the reader by reflecting the wave (passive tag) or transmitting a radio wave back to the reader (active tag)[1]. The data that tag sends to reader is the information about the object to which the tag is attached. On tag's side, the chip will control the communication process. On reader's side, a computer will manage all information received by readers.

Active tags have their own power supplier and operate mostly in UHF bands which offers good balance between range and performance. The distance can be as far as hundreds of meter. Because of these advantages and rapid grow of active RFID system in near future, this thesis concentrates to active RFID system.

Fig. 1.2 shows the processes in designing an RFID system.

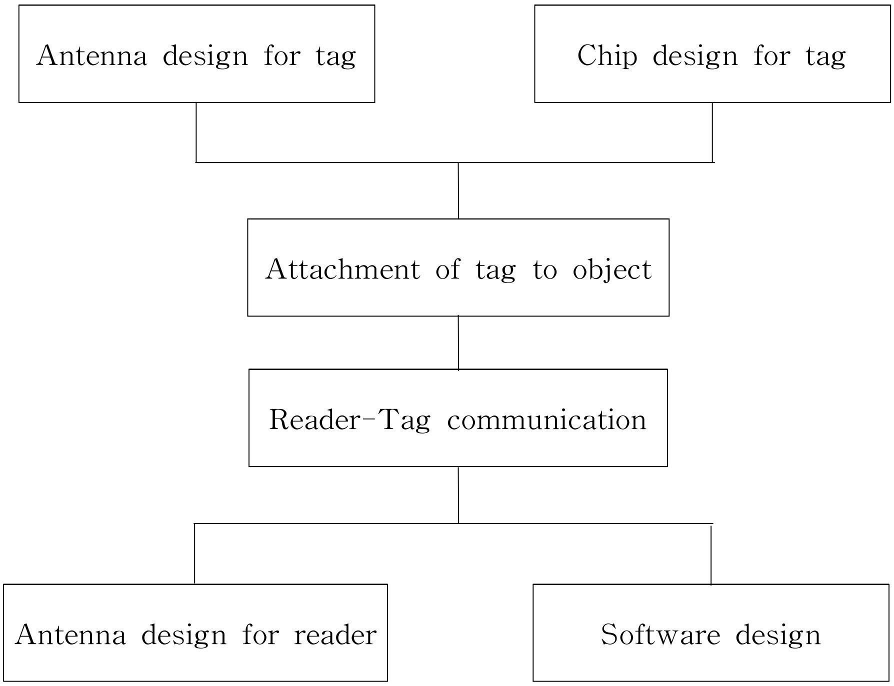


Fig. 1.2 Design processes of an RFID system

The challenges which could be met in each process:

a. *Antenna design for tag*

- Omni-directional radiation pattern (so that the tag can be easily identified from any direction)
- High gain
- Small size (to reduce the price, easy to mount)
- Wideband (for UHF bands 860 MHz - 960 MHz)
- Can be attached to any kind of object (various kinds of material)
- Matching with chip impedance

b. *Chip design for tag*

- High sensitivity
- Matching with antenna impedance

c. *Attachment of tag to object*

- Change of quality factors of the tag antenna, e.g. radiation pattern, gain, etc.

d. *Reader-Tag communication*

- Recognize the tag (communication protocols, anti-collision protocols, error detection, etc.)
- Quality effected by the changes in environment (changes in tag when is attached to the object, changes in surrounding environment, e.g. weather, obstacles, etc.)
- Reader management (location of readers)

e. *Antenna design for reader*

- High gain
- Omni-directional or directive pattern (depends on application)

- Handheld (depends on application)

f. Software design

- High accuracy
- High speed
- Database management

1.2 Objective

My long-term objective toward Ph.D degree is developing a completed active RFID system including tag and reader subsystems, and then investigating as well as enhancing the performance of the system. Hence, the work steps are:

- how to design antenna for tag and meet the requirements as well as balance the trade-offs among antenna properties.
- how the environment affects to quality of communication between reader and tag.
- how to design antenna for reader (often array antennas), and locate the readers as well as manage the data received from readers.
- design a completed RFID system

Therefore, in this Master thesis, I concentrate to first two steps. Some problems and solutions in designing antenna for the tag will be presented in Chapter 2. In Chapter 3, the communication between tag and reader is modeled in case of one container yard and simulated to see the effects of multipath to the received signal. Chapter 4 will give conclusions to the first two steps and propose the next work.

Chapter 2. Design of Tag Antenna

2.1 Background and Objective

2.1.1 Objective

As mentioned in Chapter 1, designing the antenna for tag is really an interesting but difficult matter with many requirements have to satisfied, even when they are conflicted to each other.

First, frequency for the antenna is chosen at 433.92 MHz, because in the UHF bands, which offers good balance between range and performance, it offers many unique advantages as an RFID frequency, such as an effective frequency, and authorized for RFID system use in many countries; ability to co-exist with other devices in the system[2].

Second, the discrete goals for the antenna have to be clear.

- The omni-directional pattern is the must-have characteristic.
- Impedance matching between antenna and chip is not serious. In case of passive tag, due to the rectifier layer inside the chip, which is used to receive the power from the radio wave to supply for its own activities, the impedance of chip has a high capacitive reactance. So, the impedance matching between antenna and chip is a serious problem in passive tag. However, in case of active tag, the role of rectifier is not important and can be ignore because the active tag has a power supplier for itself.

- Other requirements for high gain, but wideband and small size is really a matter because these properties of antenna is trade-off. We have to balance these parameters in a range that satisfies the active RFID system.

2.1.2 Analysis

The omni-directional characteristic is rather easy to achieve with using omni-directional antenna types like monopole, dipole, patch, etc.

Regularly, consumers expect that the electronic devices is provided with impressive improvement in size reduction for simplicity and mobility, especially in case of RFID tag in mobile RFID system or Ubiquitous Sensor Network (USN). Hence the small size is often paid attention in antenna design. And so, small size is the most important goal in the design.

There are many kinds of small antenna such as planar inverted-F antenna (PIFA), chip antenna, patch antenna, and etc. For those electrically small antennas, especially in low frequency range, some kinds of problem are arisen such as:

decrease of radiation resistance, in other words, decrease of efficiency.

increase of input impedance due to increasing reactance, and input resistance is often very low, causing impedance mismatch problem. This problem can be solved by adding loss. In addition, bandwidth is limited by impedance mismatch.

increase of effect from surrounding environment.

the efficiency is reduced also because power is trapped in a limited space with high density.

The fundamental limits on antenna size have been studied since 40s when Wheeler[3] and Chu[4] presented a mathematical relationship between antenna size and Q. Because this limit cannot be changed, the solutions for this problem can be:

sharing the resource with radiated part (such as use printed circuit board for ground plane in embedded antenna, etc.).

optimize the topology of radiating elements, fully utilize the volume for antenna.

using new electromagnetic material

system solutions (such as smart antenna, etc.)

The remain requirement is the gain and bandwidth. We need to control the trade-off between them.

2.1.3 Choice

From the above analysis, it is suggested that we use magneto-dielectric material in antenna design. Magneto-dielectric material is one kind of dielectric material whose value of permeability can be varied easily. It is different from conventional dielectric in which the permeability is unit. With the presence of permeability, the bandwidth and gain of the antenna can be adjusted. By controlling the ratio between permeability and permittivity, the gain-bandwidth product, one factor to evaluate the quality of antenna, can be changed to meet the requirement.

In magneto-dielectric material, both ϵ_r and μ_r are complex number described as:

$$\epsilon_r = \epsilon' - j\epsilon'' = \epsilon'(1 - \tan\delta) \tag{2.1}$$

$$\mu_r = \mu' - j\mu'' = \mu'(1 - \tan\delta') \tag{2.2}$$

where $\tan\delta$ and $\tan\delta'$ are dielectric loss tangent and magnetic loss tangent, respectively.

The magneto-dielectric composite consists of some metallic components and/or ferrite material, so that the permeability of dielectric can be changed easily. Unfortunately, magnetic losses of the material are rather high, due to the presence of those metal and ferrite components.

In general, microstrip antennas are half-wavelength structures and are operated at the fundamental mode TM_{01} or TM_{10}, with the resonant frequency given by [5]

$$f \cong \frac{c}{2L\sqrt{\mu_r \epsilon_r}} \tag{2.3}$$

where $n = \sqrt{\mu_r \epsilon_r}$ is called miniaturization factor, or refractive index.

Most microstrip patch antenna designs until now are based on the dielectric which is just changed the permittivity. If conventional dielectric ($\mu_r = 1$) is used, the ϵ_r is required at very high value in order to increase the refractive index, so that the size of antenna is reduced. This makes the antenna design procedure simpler because only one parameter of dielectric coefficients affects to antenna performance. In another hand, this limits the ability of easily improving the performance of antenna, and this causes some disadvantages such as narrow bandwidth and low efficiency with the high value of permittivity. Thus, magneto-dielectric material offers a little more number of parameters of dielectric in order to change the performance of the antenna.

In case of magneto-dielectric material substrate, to achieve the same value of n (the same size of antenna), μ_r and ϵ_r can be chosen at moderate values[6]. Thus, the field confinement is minimized and the medium is far less capacitive. Moreover, the permeability value which is different from unit in this dielectric also leads to some advantages as described below.

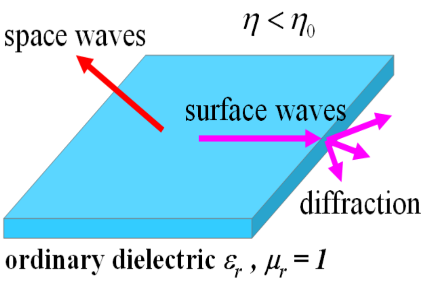


Fig. 2.1 Comparison between two kinds of dielectric.

Fig. 2.1 shows the comparison between ordinary dielectric and magneto-dielectric material. η is intrinsic impedance of dielectric and η_0 is intrinsic impedance of free space, where

$$\eta = \eta_0 \sqrt{\mu_r / \epsilon_r} \tag{2.4}$$

So, if the ratio between μ_r and ϵ_r becomes to 1, the matching between two intrinsic impedances is reached, or the characteristic impedance of magneto-dielectric material medium is close to that of the surrounding medium, it allows for ease of impedance matching over a wider bandwidth and suppression of the surface wave[7], and the efficiency of antenna increases, as the consequence. The interaction of environment is eliminated. Hence, using magneto-dielectric material, many advantages can be achieved just by adjusting the permeability and permittivity.

In addition to using of new material, meander line technique is also used to one more time reduce the size and utilize whole volume of the antenna.

2.2 Antenna Design

2.2.1 Miniaturization

One example of patch antenna is presented to prove the ability of miniaturization from using magneto-dielectric material. In addition, its resonant frequency is 433.92 MHz and has omni-directional radiation pattern. The antenna type is meander type, but the usage of magneto material as dielectric can be used for any kind of antenna.

Fig. 2.2 shows the structure of antenna, using probe feeding method.

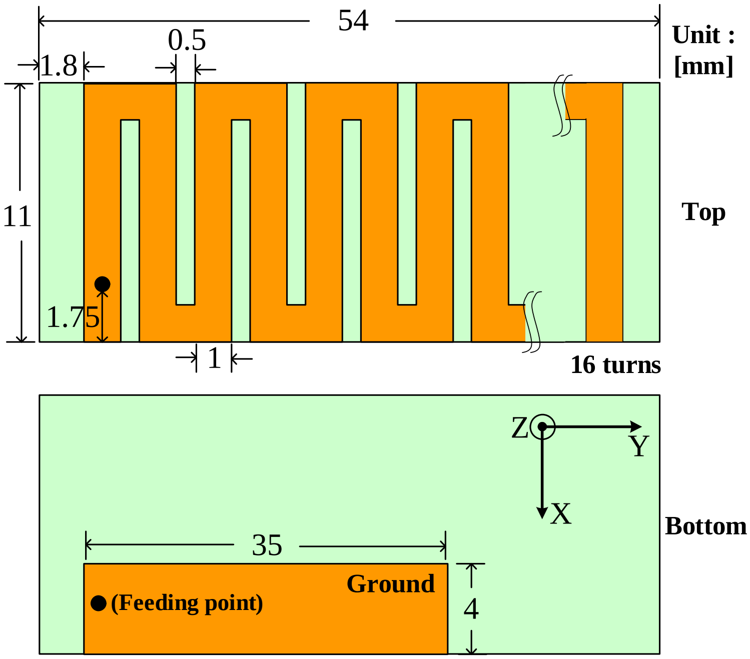


Fig. 2.2 Structure of antenna

The upper metal plate contains a meander line structure with 16 turns. The line width is 1 mm and the gap between two adjacent meandered sections is 0.5 mm. In the bottom metal plate, the ground size is also kept reduce to expect an omni-directional pattern. The permittivity and permeability is chosen at 5.21 - j0.012 and 2.39 - j2.58 (one kind of Ni-Zn material). The thickness of the substrate is 1.6 mm. The return loss of this initial model is shown in Fig. 2.3 (circular-marked line).

Maintaining the antenna structure like in Fig. 2.2, the properties of magneto-dielectric material are changed to optimize the performance for the antenna. The aim of this parameter study is finding the optimized values of μ_r and ϵ_r so that the antenna resonates at 433.92 MHz with a low return loss level. The results of return loss when varying the permittivity of magneto-dielectric is shown in Fig. 2.3.

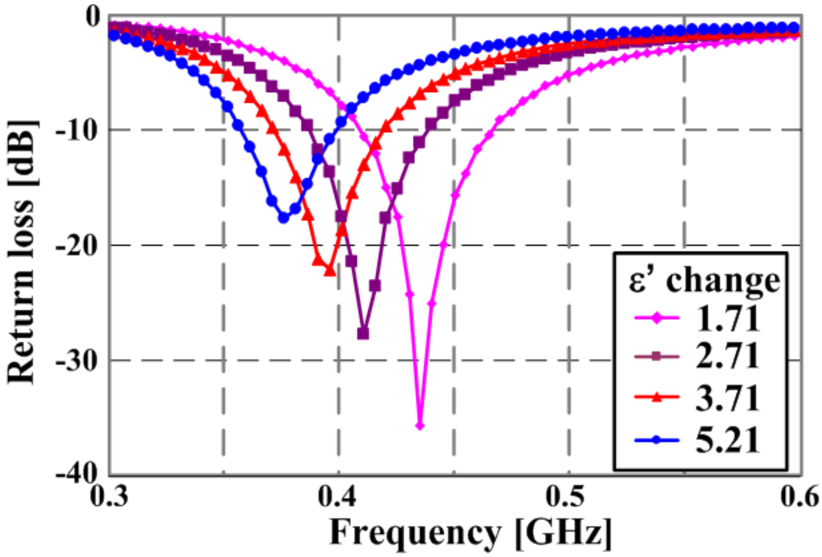


Fig. 2.3 Return loss against permittivity change

It can be seen that when dielectric constant increases, the resonant frequency shifted to low frequency area. At $\epsilon' = 1.71$ (rectangular-marked line), good resonant characteristic is earned with return loss of meander line antenna is -30 dB at 433.92 MHz.

Second, in the permittivity component, only ϵ'' is changed. Value ϵ' is fixed at 1.71 and permeability is not changed. The effect of ϵ'' changing applies only to return loss level as shown in Fig. 2.4.

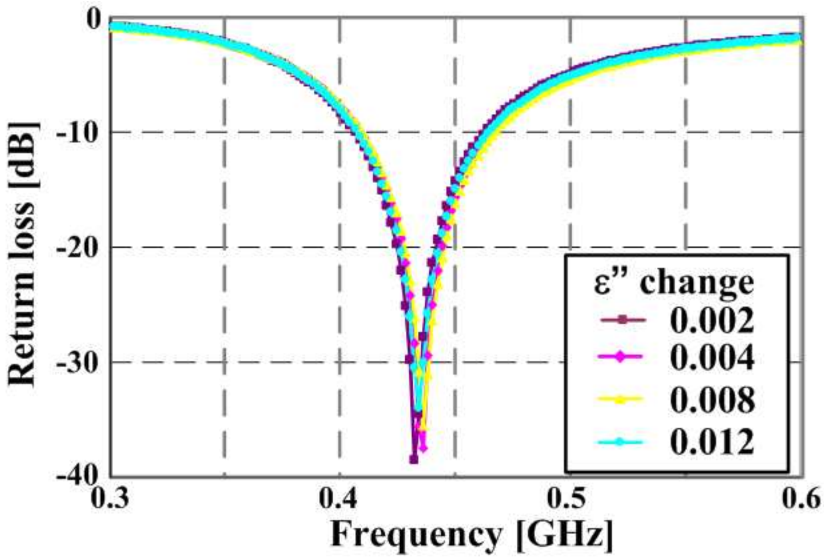


Fig. 2.4 Return loss against dielectric tangent loss change

The resonant frequency is almost same. It means that this loss property just affects to the efficiency of the antenna. To have the best return loss, 0.004 is chosen for ϵ'' value.

Fig. 2.5 and Fig. 2.6 show the results of the permeability components of magneto-dielectric variation, μ' and μ'' respectively, to return loss, when $\epsilon_r = 1.71 - j0.004$.

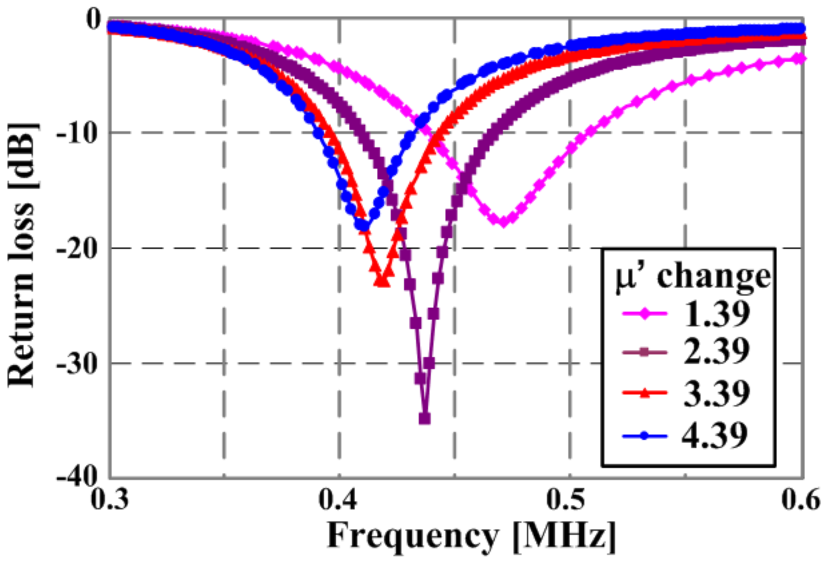


Fig. 2.5 Return loss against permeability change

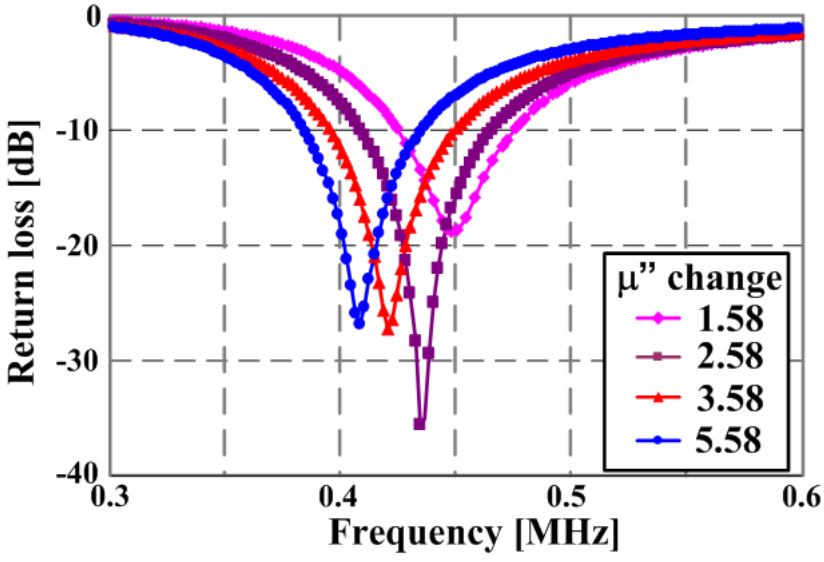


Fig. 2.6 Return loss against magnetic tangent loss change

From Fig. 2.5, when the permeability increases, the resonant frequency of antenna is lowered. This effect is well-known, similar with the change of permittivity. A good performance at 433.92 MHz is observed in the case of rectangular line.

In Fig. 2.6, different with the change of ϵ'', μ'' participates in changing resonant frequency. It is because of mutual coupling between adjacent sections, the magnetic tangent loss makes change to equivalent inductance of the meander line, and so to resonant frequency of the antenna. The values of μ'' are chosen from database of popular magneto-dielectric material properties. These values are rather high. It is a disadvantage of magneto-dielectric material. The high loss affects to efficiency, or gain, of antenna as shown in Fig. 2.7.

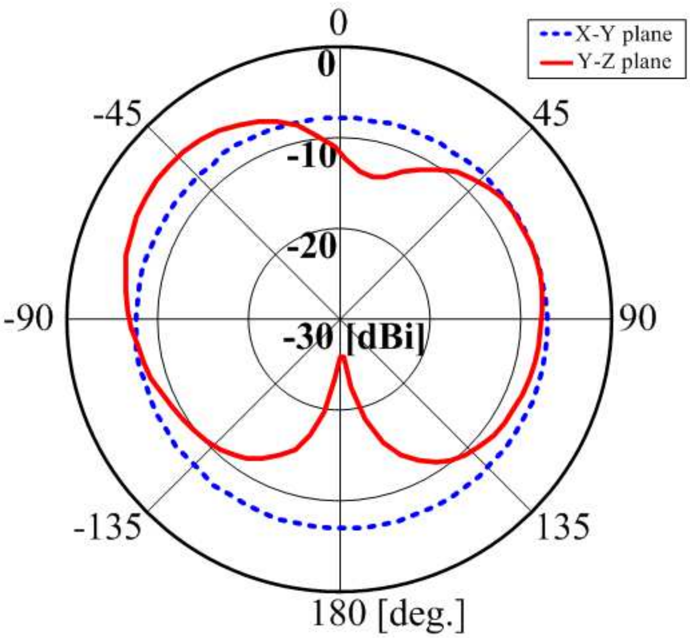


Fig. 2.7 Gain pattern of antenna at 433.92 MHz

The gain limitation for small antenna has been expressed by Harrington in reference number [8].

$$G = (ka)^2 + 2(ka) \tag{2.5}$$

where k: wave number

a: radius of smallest sphere encompassing the antenna

In this case, the maximum attainable gain of this size of antenna is 0.55 dBi. From Fig. 2.7, the maximum gain of the antenna is -4.3 dBi. However, compared with other designs in the same resonant frequency in reference number [9], the gain reduction is not much as miniaturization of antenna size.

The optimized parameters of magneto-dielectric substrate is achieved with the value of permittivity at $\epsilon_r = 1.71 - j0.004$, and the value of permeability at $\mu_r = 2.39 - j2.58$. The small antennas techniques are generally used dielectric with high permittivity. However, proposed meander antenna has low permittivity constant of 1.71, but the results show good performance while the size reduction ratio is still high.

This antenna design has omni-directional characteristic. As seen from Fig. 2.7, it is omni-directional in XY-plane. In ZX-plane, because of the existence of the ground, there is a null point. However, the half power beamwidth is also very large.

2.2.2 Gain-Bandwidth trade-off control

Gain-bandwidth product (GBP) is one of factors usually used to describe the relative quality of an antenna [7]. It is defined as a product of gain and bandwidth of the antenna.

$$\text{GBP} = \text{Gain} \times \text{Bandwidth} \tag{2.6}$$

where gain is dimensionless and unit of bandwidth is Hz. It is noticed that the gain calculated in dB (or dBi, dBd) cannot be used in this equation, because the sign of gain in the dB scale, which can be both positive and negative, may cause a wrong comparison.

It is well-known that gain and bandwidth is trade-off. Some designs concentrate on improving the bandwidth, so the gain decreases as a consequence. Other designs aim to increase the gain of antenna and pay a price for narrow bandwidth. Hence, any design with the goal of enhancing the antenna quality must have actual improvement of GBP.

From reference number [10], the zero-order bandwidth for an antenna over a magneto-dielectric material substrate can be approximated by:

$$BW \approx \frac{96\sqrt{\mu_r/\epsilon_r}\,\dfrac{t}{\lambda_0}}{\sqrt{2}\left[4+17\sqrt{\mu_r\epsilon_r}\,\right]} \tag{2.7}$$

where t : thickness of the substrate

λ_0: wavelength at resonant frequency

It is easily seen that when the permittivity-permeability product is kept, i.e. the size of antenna is unchanged because of refraction index n, the bandwidth of antenna can be broader by increasing the ratio between permeability and permittivity.

It is quite an interesting matter. The size of antenna is still small, and the quality can increase just by changing the parameters of substrate. Therefore, in the following, the effect of μ_r/ϵ_r to GBP is analyzed because it affects not only to bandwidth but also the gain of antenna. The product $\epsilon_r \mu_r$ is kept constant at 4.087. The values of μ_r and ϵ_r are changed. Each pair of (μ_r, ϵ_r) value forms one material. There are 7 different cases are calculated. The resonant frequency at each case is checked that they are nearly the same. Variance of GBP against μ_r/ϵ_r is shown in Fig. 2.8, and detailed values are presented in Table I.

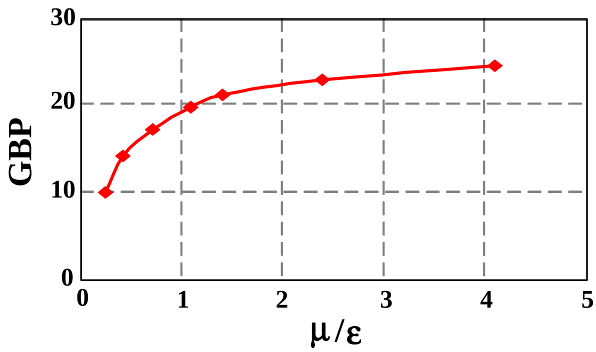


Fig. 2.8 GBP against permeability-permittivity ratio

TABLE I

Gain-Bandwidth Product Analysis

Material	μ_r/ϵ_r	Gain (dB)	Gain	BW (MHz)	GBP
①	**4.087**	-2.70	0.537	46	**24.702**
②	**2.382**	-3.45	0.452	51	**23.052**
③	**1.398**	-4.34	0.368	58	**21.351**
④	**1.089**	-4.71	0.338	59	**19.942**
⑤	**0.715**	-5.39	0.289	60	**17.344**
⑥	**0.420**	-6.10	0.245	58	**14.210**
⑦	**0.245**	-6.52	0.223	45	**10.035**

From Fig. 2.8, it is obviously seen that GBP always increases when μ_r/ϵ_r increases. The limited range for both variations of μ_r and ϵ_r is from 1 to 4.087. The slope degree of the graph is high when μ_r/ϵ_r is in the range from 0 to 1.5. After that, the graph has saturation trend.

The gain of antenna always increases, but the bandwidth has a peak value. When μ_r/ϵ_r is around 1, the bandwidth is nearly unchanged, while the gain still increases. It is because when μ_r/ϵ_r closes to 1, the impedance contrast between dielectric and surrounding free space is much reduced, so the efficiency increases. Although bandwidth does not increase continuously like gain, the quality of antenna is still improved because GBP always increases. That is the advantage of magneto-dielectric material.

2.3 Summary

This chapter consider about the design of antenna for active RFID tag. The chapter reviews all the challenges and possible solutions for them. One design of antenna is shown to describe in detailed about the design process with selected techniques.

The usage of magneto-dielectric material is proposed to satisfy almost requirements. The antenna resonates at 433.92 MHz with return loss, bandwidth are respectively -38 dB, and 58 MHz, as well as omni-directional pattern while the overall dimension is just $0.078\lambda \times 0.016\lambda \times 0.0023\lambda$. This size is achieved by choosing the optimized values of 4 substrate's parameters, i.e. $\epsilon', \epsilon'', \mu', \mu''$. The antenna structure is meander line type, but this method can be applied for any other antenna structures.

The maximum gain of the proposed antenna is -4.3 dBi, rather low. This is mainly because of the high concentration of electric and/or magnetic fields within a small volume of antenna structure due to small size, in addition to a lossy material as magneto-dielectric material.

Moreover, magneto-dielectric material has another advantage, i.e. the quality of antenna can be adjusted by controlling the ratio between permeability and permittivity (μ_r/ϵ_r). The best trade-off between gain and bandwidth is obtained when this ratio is a little greater than 1. If this ratio increases, the antenna quality increases, but the price is decrease of bandwidth.

Therefore, where the size of antenna is much more important than other properties, magneto-dielectric is suggested to use for miniaturization.

Chapter 3. Tag Tracking System Modeling in 3-dimension

3.1 Background and objective

A. The important role of modeling and simulation

The complexity of modern communication systems is a motive power for the popular use of simulation. This complexity results both from the architecture of modern communication systems and from the environments in which these systems are deployed.

An important motivation for the use of simulation is that simulation is a valuable tool for gaining insight into system behavior. A properly developed simulation is much like a laboratory implementation of a system. Measurements can easily be made at various points in the system under study. Parametric studies are easily conducted, the effects of parameters′ changes on system performance can be obtained without difficulty. It is also easily display the results graphically in many forms from waveform in time-domain to spectrum, histograms, etc. Most importantly, “what if” studies can be performed using simulation more easily and economically than with actual system hardware.

In case of active RFID system, when the price of existing systems in the world is very high, as well as RFID system is affected much from surrounding environment, modeling and simulation is a proper choice for experiment and evaluation before making a real system.

B. Objective

RFID is also a wireless communication system, so the block diagram of the model for RFID system is like below:

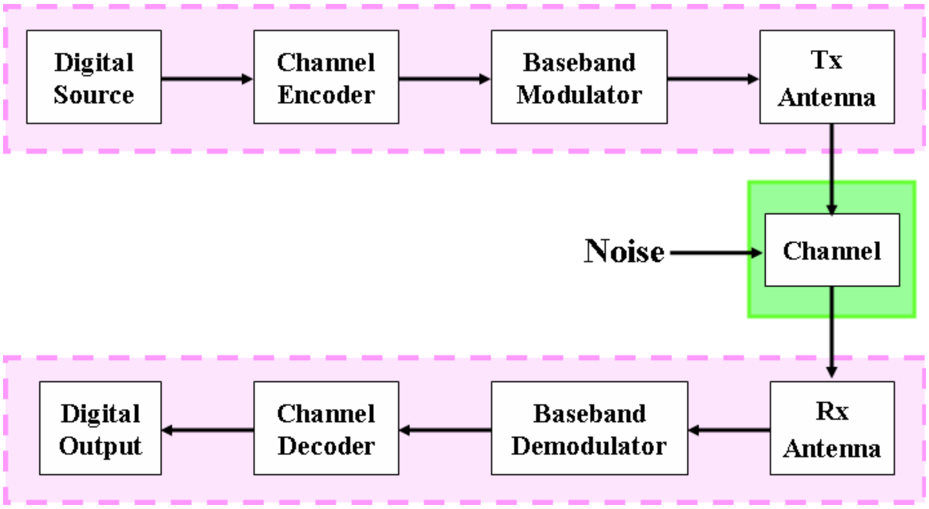


Fig. 3.1 Block diagram of wireless communication system

This block diagram consists only most basic and important parts of the system, so that we can have an overview about the system. Various kinds of wireless system are also have the same structure, but the different part is channel model. Every system has its own characteristic of the communication process. That is why the transmitting part and receiving part can be the same, but the performance of the system will be different if the communication is conducted in different environment. Channel modeling is the most important part of modeling wireless system in general, and RFID system in particular.

Therefore, the objective of this chapter is building one channel model for communication between tag and reader in a complex environment with many obstructions. In this model, the structure of an container yard is predefined, with the input is transmitted signal, and position and size of obstructions. An effective algorithm is proposed to find all the possible reflected waves inside the environment. At the output, the received signal is the summation of many version of transmitted signal after reflections from obstacles, that have just found by the above algorithm. The simulation results are compared with the measurement results in a reduced scale model.

3.2 Modeling

In this model, container yard consists of many containers is considered. In this case, the structure of the yard can be easily known. Some information like the number of container, the positions of containers, located position of reader and tags, etc. are known. The problem is the answer for two questions:

- How can the signal from reader arrive to the tag?
- What is the effect of many obstacles like containers?

In this model, the two questions will be solved. The container faces are assumed as metal reflection planes. The radio waves from the reader are transmitted to every direction in the space. This waves can arrive at tag, or arrive at container, ground, etc. When they arrive at other obstacles, they are reflected. This reflection cause the change of signal in direction, signal strength, and phase. Some of this kind of signal will arrive at the tag also. Therefore, received signal at the tag is the summation of all direct wave and reflected waves.

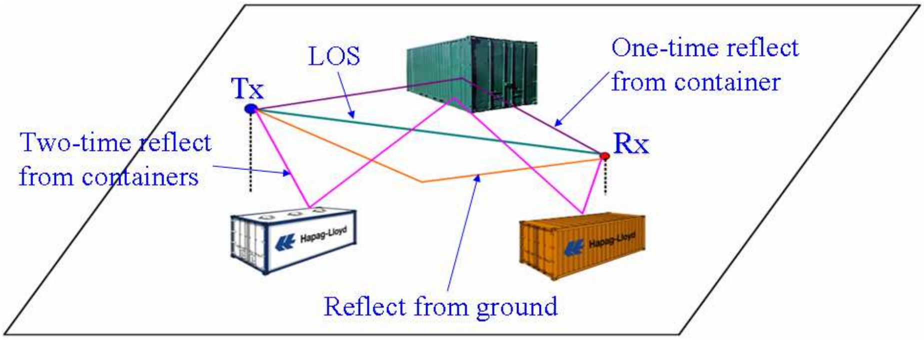


Fig. 3.2 Direct wave and reflected waves

So, the consideration of received signal consists of two tasks:

- Find all the waves that can be arrived at the receiver of the tag.
- Summation of all those waves.

A. Algorithm to find reflected waves

Because the circumstance is known, it is called the site-specific model, one suitable method can be applied to this case is ray-tracing method. Originally, this method is often used in optical application. However, in radio propagation between two points, this method is also applicable and very useful.

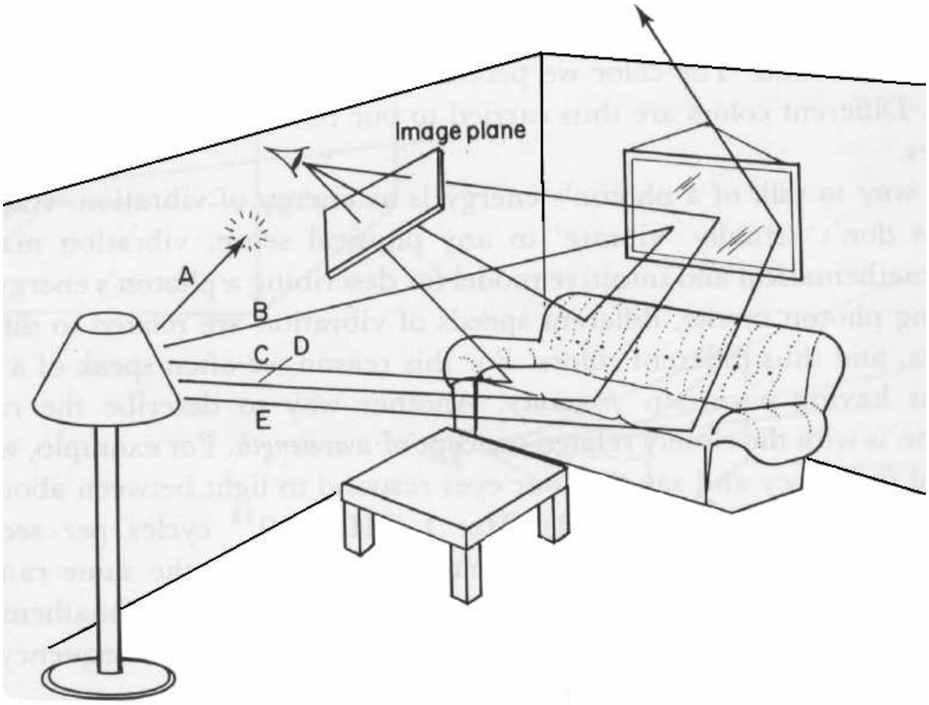


Fig. 3.3 Ray-tracing method [13]

As shown in Fig. 3.3, the transmitter is assumed to radiate "rays" at every direction. With each ray, its propagation path is observed (followed, or traced) as it bounced around the environment, until it reaches the observation point or get out of the analysed environment. As we can see, the path A is called the direct wave, and the three paths B, C, D can arrive at the image plane as we expected, except the path E cannot arrive at the observation point. More specifically, it is called forward ray tracing; that is we follow the waves from their origin of radio source and into the environment, tracing their path in a forward direction, just as the waves would have travelled.

The principle of this method is very simple for easy to understand, and effective, especially for reflection phenomenon. However, it has an drawback of computational expense, and we cannot trace the wave at every direction. The specific algorithm for tracing in the most effective way must be built depending on each application.

Hence, return to our case, one effective algorithm is needed to develop to find the waves arrived at the tag. In here, I suppose three ideas to reduce the calculation complication.

1. The reflection happens at everywhere has a plane. So, we consider only at available reflected planes.

2. Like the light, a "wave beam" hits to a plane will reflect as a beam (Fig. 3.4). So, we consider every beam at each time.

3. One "wave beam" is bounded by faces. These faces are formed from several rays which is the rays come at the vertices. This means we can represent all rays reflected at one plane just by several rays. This is the key point of my proposed algorithm.

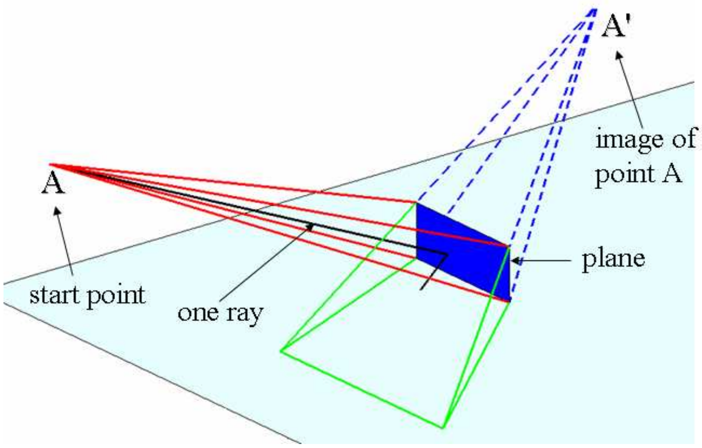


Fig. 3.4 Reflection at a plane

In this algorithm, we consider the perfect reflected planes. So, the technique to specify the reflected rays is based on the image point technique, as shown in Fig. 3.5.

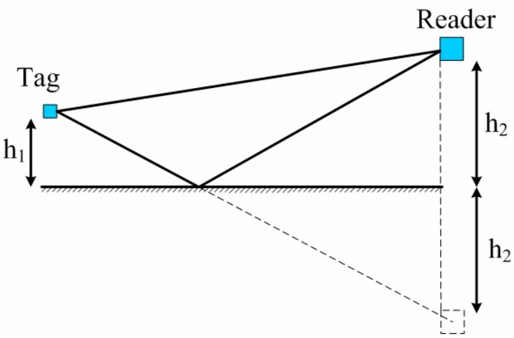


Fig. 3.5 Using image point to determine the reflected point

We also note that there is reflection from the ground. To solve this, we can simply consider as there are another radio source at the position of image point of reader through the ground.

The following is an example to visually present the above algorithm.

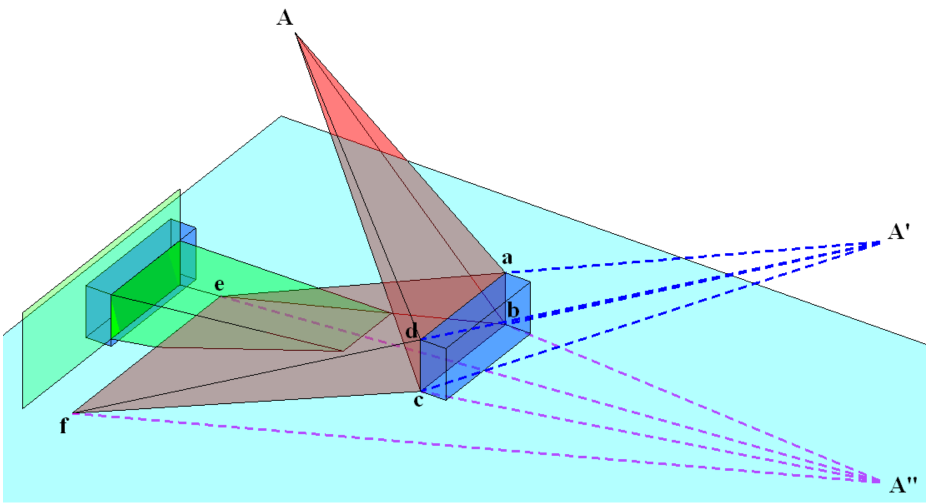


Fig. 3.6 Wave beams

In Fig. 3.6, the source point is at A. There are two obstacles. The red beam is the coming wave beam to the right obstacle. This beam is represented by 4 rays Aa, Ab, Ac, and Ad. The reflected wave beam (dark red color) is found by using image point A′ of A through the plane. This reflected wave beam is represented by 4 rays: ae, be, df, and cf. This reflected beam continues reflecting at the ground (green color, found by the image point A″ of A′ through ground) and arrive at the left obstacle.

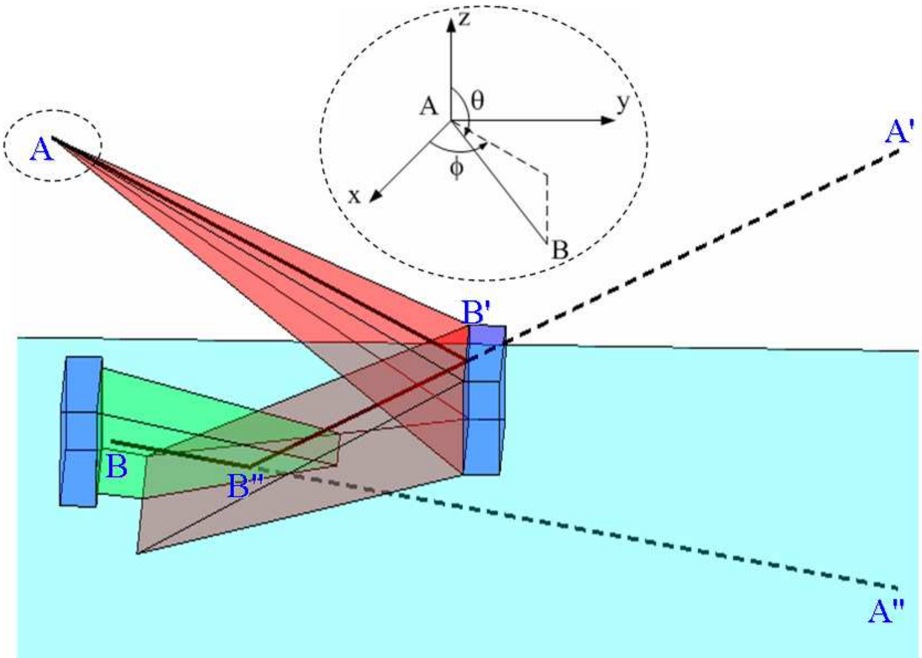


Fig. 3.7 Extract the ray

The meaning of this process is identifying the space volume that the wave from A can reach. For example, in Fig. 3.7, if there is a point B inside the green beam, there is a ray come from A to B. B is inside green beam, so, it is defined by A″.

The intersection of line A″B and the ground will determine the reflected point B″ in the ground. Next, B″ is inside dark-red beam, so, the intersection of A′B″ will determine the reflected point B′ at the plane. Finally, we found the wave go from A to B′, reflected at the face (abcd) to B″, then reflected one more time at the ground to B. This explains how we can extract the ray from the wave beam that we already found before. Moreover, with exact position of A, B′, B″ and B, we can calculate the direction (θ, ψ) of the ray so that it can be looked up in the gain pattern of antenna for the gain at that direction, and supplied to the equations as following.

B. Summation of all waves at the receiver

When radio wave propagates from one point to another point in the free space, its amplitude will be degraded according to the distance. It also takes a period of time to go from source point to destination point, we call that time the delay time. If the transmitted signal is $y(t)$, then the received signal will be calculated from equation 3.1.

$$r(t) = a_0 y_{LOS}(t-\tau_0) + \sum_{1}^{s} a_i y_{REFi}(t-\tau_i) \tag{3.1}$$

where:

- $y_{LOS}(t)$: direct wave
- a_0 : the degradation of amplitude of direct wave
- τ_0 : the delay time of the direct wave (s)
- a_i : the degradation of amplitude of each reflected wave
- τ_i : the delay time of the each reflected wave (s)
- s : number of reflection paths

The degradation of amplitude and the delay time is calculated from equation 3.2 and 3.3.

$$a_i = \left(\frac{\lambda}{4\pi L_i}\right) G_{si}(\theta_{si}, \psi_{si}) G_{ri}(\theta_{ri}, \psi_{ri}) \tag{3.2}$$

$$\tau_i = \frac{L_i}{c} \tag{3.3}$$

where:

- L_i: distance from source to receiver (m)
- $G_{si}(\theta_{si}, \psi_{si})$: gain of the ray transmitted from source antenna at (θ_{si}, ψ_{si}) direction (dimensionless)
- $G_{ri}(\theta_{ri}, \psi_{ri})$: gain of the ray received at receiving antenna at (θ_{ri}, ψ_{ri}) direction (dimensionless)
- c : light velocity (m/s)
- λ : wavelength (m)

From the received signal, the received power can be calculated from equation 3.4.

$$P_r = \int_{\Delta T} \frac{|r(t)|^2 dt}{\Delta T} \tag{3.4}$$

where ΔT is a period of time.

3.3 Simulation

The algorithm is coded by Matlab to simulate for verification. Matlab is chosen because it has useful built-in functions and routines especially used in communication field. Besides, it provides a wide range and flexibility for display in 3-dimension.

The simulation program will be applied to an simple example system as shown in Fig. 3.8.

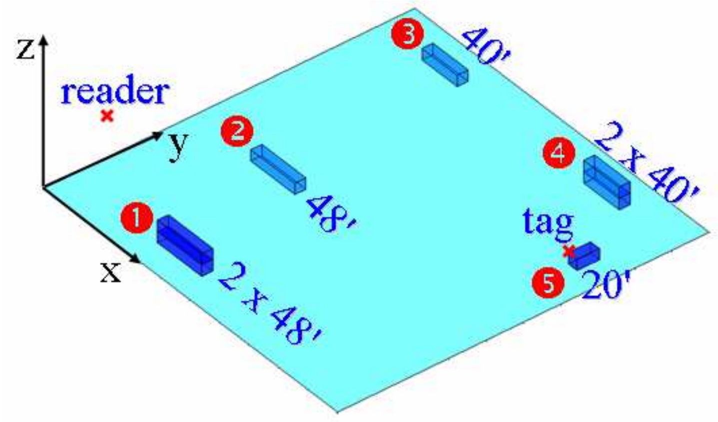


Fig. 3.8 An example of container yard

In this model, input data includes:

position of reader and radiation pattern of reader antenna

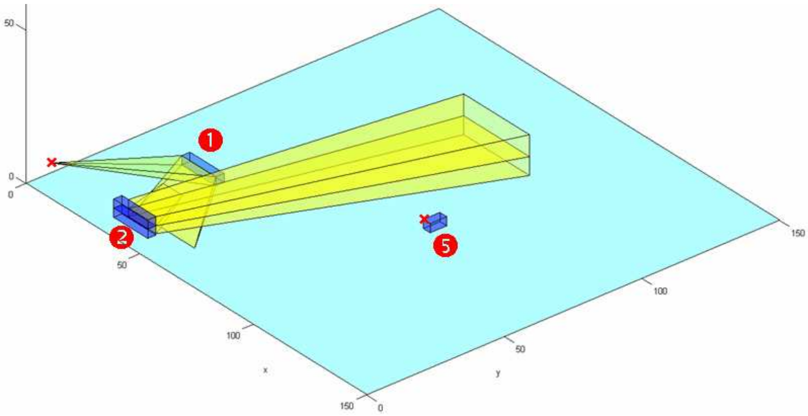
position of tag and radiation pattern of tag antenna

position of eight points defining the position and size of each containers. In this example, there are three 48-feet containers at potition 1 and 2, three 40-feet containers at position 3 and 4, and one 20-feet container at position 5 to which the tag is attached.

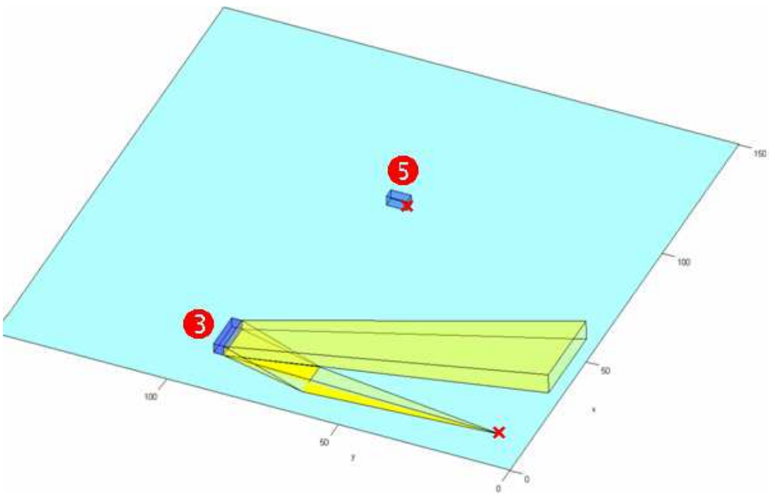
First, the simulation program will be run to find all possible propagation paths between reader and tag. Second, the signal arrived at tag will be summed and calculate the received power. The received power is calculated so that we can compare simulation results with measurement results.

A. Find possible propagation paths

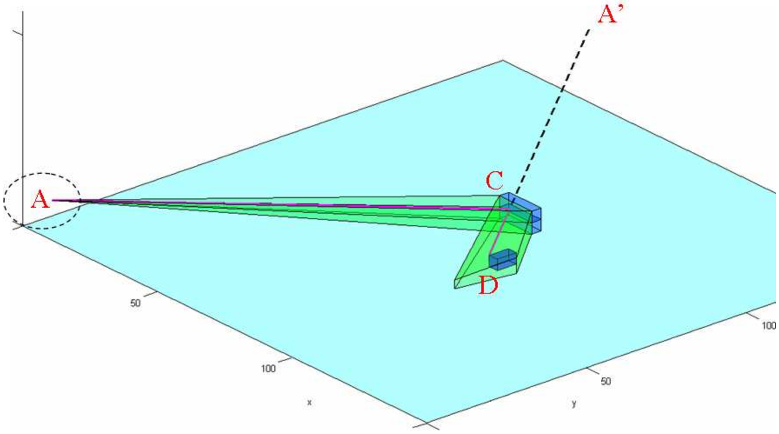
All beam and reflected beam at each plane (of containers) are shown in Fig. 3.7 (a-d). Actually, the simulation program will find all simultaneously. However, in order to display for easy to understand, the beam at each plane is display separately, except for containers at position 1 and 2 because the reflected beam from container at position 2 goes to and reflects at containers in position 1.



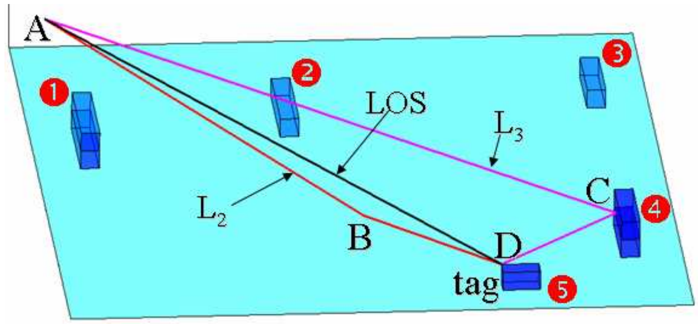
(a) Reflected beams at containers at postion 1 and 2



(b) Reflected beams at containers at postion 3



(c) Reflected beams at containers at postion 4



(d) All propagation paths

Fig. 3.7 All beam and extract the propagation paths

Firstly, we check the light-of-sight path and the reflected path directly from the ground to the tag. There are both these two paths. Next, from Fig. 3.9(a), and Fig. 3.9(b) we can see that the radio wave cannot reach at the tag after reflected from these containers. Fig. 3.9(c) shows the reflected beam at containers at position 4 can arrive at the tag. From this beam, we extract one more propagation path. So, finally we have 3 paths as shown in Fig. 3.9(d)

B. Compare with measurement results

We use received power to compare simulation results with measurement results for verifying the accuracy of the algorithm, because we do not have enough equipment to show another parameters such as the signal, or the bit error rate (BER) of the communication process.

Besides, we notice that the actual size of container yard is very big, hundreds of meters. In this example, the size is assumed of 150 m x 150 m. We have to reduce this size 30 times for measurement in anechoic chamber. Hence, the frequency is also needed to proportionally increase from 433.92 MHz to 13 GHz. Moreover, the transmit signal is analog sine function. So, in the simulation program, these parameters must be followed. The settings for measurement is shown in Fig. 3.10.

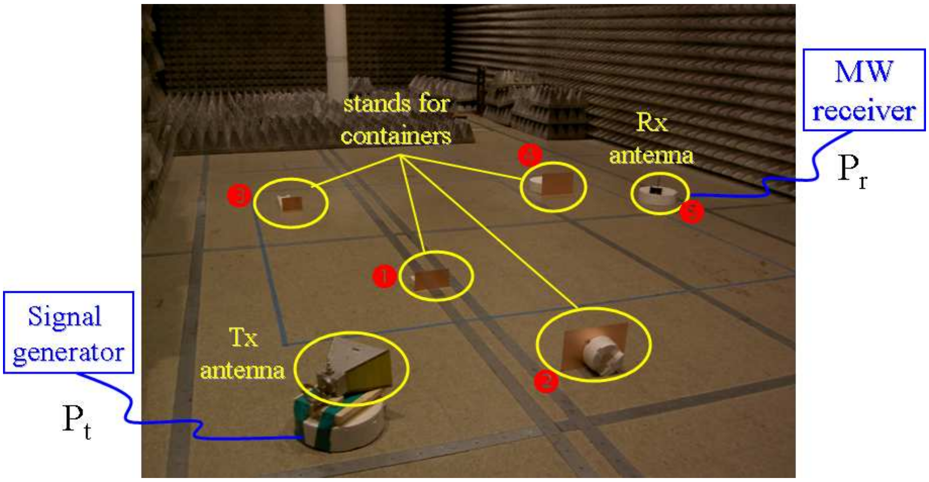
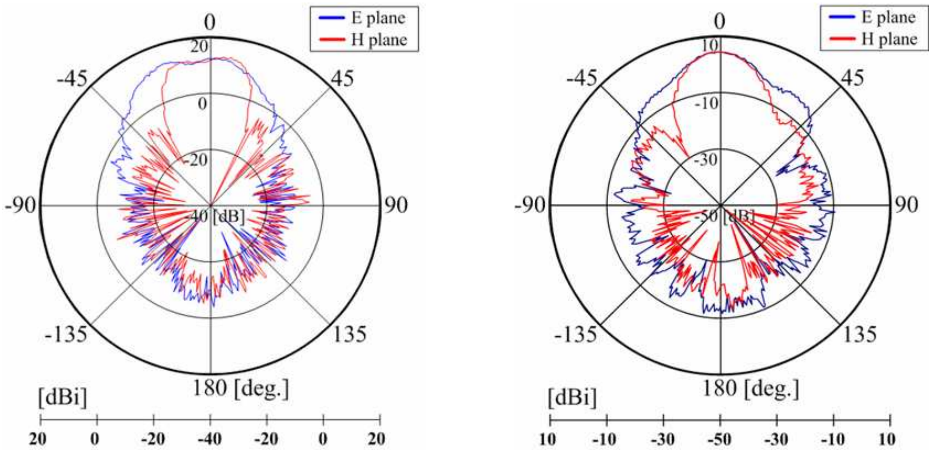


Fig. 3.10 Configuration of measurement

Signal generator controls the transmitted power. The obstacles are at positions stands for containers (the sizes are also reduced 30 times). Received power is monitored by microwave receiver.

The gain patterns of two antennas are measured, and saved as text file for the program looking up in calculation process. The gain patterns of the two antennas in H-plane and E-plane at 13GHz are shown in Fig. 3.11 for reference. One antenna has maximum gain of 13dBi used as reader antenna and the other has maximum gain of 5 dBi used as tag antenna.



(a) Reader antenna *(b) Tag antenna*

Fig. 3.11 Gain patterns of two antennas

In measurement, the received power is achieved by:

$$P_r = P_0 - P_L$$

where: P_r – actual received power

P_0 – received power displayed in microwave receiver

P_L – total cable loss

In simulation, the calculation process is expressed in the following.

We assume that the transmitted signal is:

$$y(t) = A_0 \sin(\omega t)$$

The transmitted power will depends on A_0.

With light-of-sight path, A-D:

$$y_{AD} = \left(\frac{\lambda}{4\pi L_{AD}}\right) G_r(\theta_1, \psi_1) G_t(\theta'_1, \psi'_1) y(t - \frac{L_{AD}}{c})$$

$$= A_0 A_1 \sin\left[\omega(t - \tau_1)\right] = A_0 A_1 \sin(\omega t - \omega \tau_1)$$

where $A_1 = \left(\frac{\lambda}{4\pi L_{AD}}\right) G_r(\theta_1, \psi_1) G_t(\theta'_1, \psi'_1)$

$G_r(\theta_1, \psi_1)$: gain of reader antenna

$G_t(\theta'_1, \psi'_1)$: gain of tag antenna

$$\tau_1 = \frac{L_{AD}}{c}$$

With the path A-B:

$$y_{AB} = \left(\frac{\lambda}{4\pi L_{AB}}\right) G_r(\theta_2, \psi_2).1.y(t - \frac{L_{AB}}{c})$$

$$= A_0 A_2 \sin(\omega t - \omega \tau_2)$$

There is no antenna at B, so the antenna gain at B is 1.

With the path A-B-D:

$$y_{ABD} = -\left(\frac{\lambda}{4\pi L_{BD}}\right).1.G_t(\theta'_2, \psi'_2) y_{AB}(t - \frac{L_{BD}}{c})$$

$$= A_0 A_2 A_3 \sin(\omega t - \omega \tau_2 - \omega \tau_3 - \pi)$$

There is the minus sign because the reflect coefficient of perfect reflected plane is -1. It means the phased is reversed.

With the path A-C:

$$y_{AC}=\left(\frac{\lambda}{4\pi L_{AC}}\right)G_r(\theta_3,\psi_3).1.y(t-\frac{L_{AC}}{c})$$

$$= A_0A_4\sin(\omega t-\omega\tau_4)$$

With the path A-C-D:

$$y_{ACD}=-\left(\frac{\lambda}{4\pi L_{CD}}\right).1.G_t(\theta'_3,\psi'_3)y_{AC}(t-\frac{L_{CD}}{c})$$

$$= A_0A_4A_4\sin(\omega t-\omega\tau_4-\omega\tau_5-\pi)$$

The received signal is the summation of three signals:

$$r(t)=y_{AD}(t)+y_{ABD}(t)+y_{ACD}(t)$$

The received power is calculated by equation (3.4) with $\Delta T=2000\,cycles$. This value is big enough to have the exact average value.

The calculation results for propagation paths are shown in Table 3.1.

Table 3.1 Calculated parameters

L_{AD} (cm)		**L_{AB} (cm)**	**L_{BD} (cm)**	**L_{AC} (cm)**	**L_{CD} (cm)**
356.93		**250.8**	**107.47**	**364.7**	**85.8**
τ_1 (ns)		**τ_2 (ns)**	**τ_3 (ns)**	**τ_4 (ns)**	**τ_5 (ns)**
357.18 (– 4.5^0)		**250.94 (–40.4^0)**	**107.54 (–121^0)**	**364.95 (129^0)**	**85.86 (92.3^0)**
θ_1, ϕ_1	**θ'_1, ϕ'_1**	**θ_2, ϕ_2**	**θ'_2, ϕ'_2**	**θ_3, ϕ_3**	**θ'_3, ϕ'_3**
0, 0^0	**0, 0^0**	**4^0, 0^0**	**9^0, 0^0**	**-2^0, 23^0**	**-4^0, -88^0**
g_r (dB)	**g_t (dB)**	**g_r (dB)**	**g_t (dB)**	**g_r (dB)**	**g_t (dB)**
13	**5**	**12.2**	**4.5**	**11.1**	**3.4**

Now, we go to compare the simulation results and measurement results to verify the correctness of the algorithm.

We note that, as shown in the result of finding propagation paths, the containers at position 1, 2 and 3 do not participate to affect the received signal at the tag. Therefore, if they are removed, the received signal is not changed. We will base on this phenomenon to compare the received power with and without containers at position 1, 2 and 3. The simulation and measurement results are shown in Fig. 3.12.

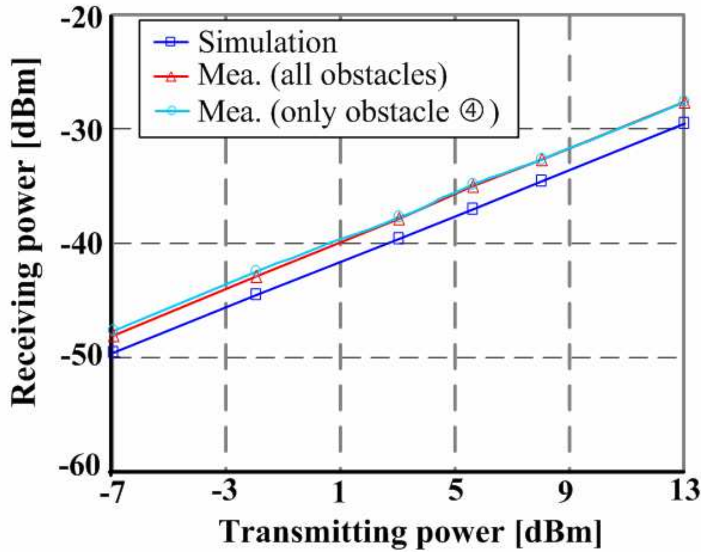


Fig 3.12 Simulation and measurement results with all obstacle and only obstacle at position 4

As we can see, the simulation result (rectangle-marked line) has the same trend with the measurement results when changing the transmitted power. The different is small because of some reasons:

- Actually in simulation, the transmitted signal is not analog as in measurement. We have to digitalize the transmitted signal.

– In addition, the setting in measurement such as position of antennas and containers, direction of two antennas, surrounding environment, etc. maybe has a little different from simulation.

The measurement results in two cases (triangle- and circle-marked lines) are also nearly the same. A very little difference is probably caused by the diffraction and scattering which are ignored in the simulation because their effect is not much.

That is the comparison on received signal. We can also check the individual paths. In here, all obstacles are removed, then there remains only light-of-sight path and direct reflection from ground. We can put an absorber at the reflection point in the ground to remove the reflection path, only light-of-sight path remains. Moreover, keeping the distance between reader antenna and tag antenna, the relative direction of the two antenna changes. The measurement and simulation results are shown in Fig. 3.13.

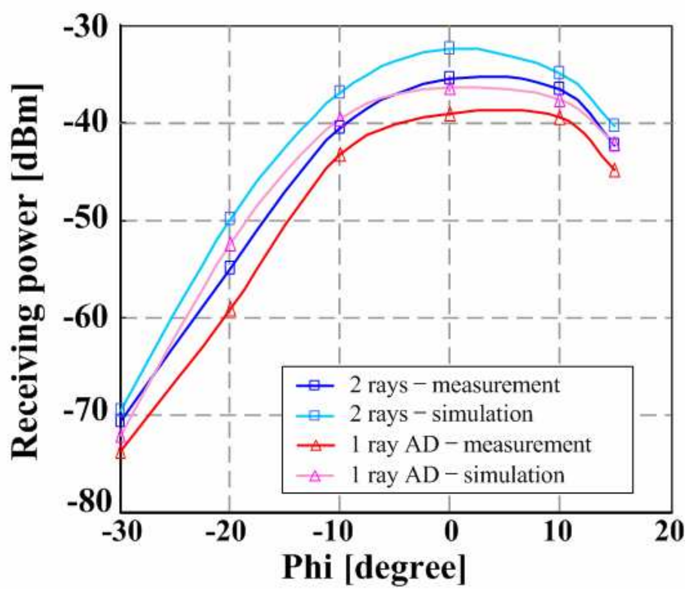


Fig. 3.13 Comparison of individual paths

In Fig. 3.13, 0^0 means the two antennas are faced at maximum gain direction. Positive degree values mean the tag antenna moves to the right, and negative degree values mean the tag antenna moves to the left. The movement causes the different direction of propagation paths, and because gain pattern of antenna is not isotropic, so the gain in changed. We can see the degradation of received power when the gain of reader antenna changes. Most important thing is the simulation results and measurement results one more time have good agreement. The difference between the two results are nearly unchanged and small.

From those comparison, we can say that the proposed algorithm is correct. Therefore, using this channel model, we can apply to simulation whole performance of RFID system.

3.4 Summary

In this chapter, an RFID system in container yard management is considered. The appearance of containers causes a complex effect to the identification performance of the tag. An effective algorithm is proposed for tracking position of the tag in this environment in order to find the factors that affects to the performance. This algorithm is based on ray tracing method to find all the communication paths between reader and tag. The simulation results using this algorithm shows a good agreement with measurement results, and this algorithm makes the analysis of the RFID system with obstacles much easier and simpler compared with conventional method.

Chapter 4. Conclusion

4.1 Done work

In this thesis, solutions for two problems in design of active RFID communication system is presented.

First, design of antenna for active tag requires many properties like omni-directional radiation pattern, high gain, small size, and can be attached to any kind of object. Some of these properties are trade-off causes a really matter in balancing the particular requirements. In this thesis, one solution of using magneto-dielectric material is proposed to miniaturize size of antenna. The process of using this kind of material in antenna design is described in detailed. The final designed antenna resonates at 433.92 MHz with return loss, bandwidth are respectively -38 dB, and 58 MHz, as well as omni-directional pattern while the overall dimension is just $0.078\lambda \times 0.016\lambda \times \times 0.0023\lambda$. Although the gain of the antenna is rather low due to the high ratio of miniaturization, magneto-dielectric material has ability to control the trade-off between gain and bandwidth while keeps antenna size and resonant frequency, just by adjusting its dielectric parameters. Magneto-dielectric is highly recommended for very small size requirement.

Second, an analytical model and a simulation model is proposed for considering communication process between reader and tag of an active RFID system in application of container yard management. Analytical model concentrates to deal with communication channel. An geographical algorithm is proposed to determine the propagation paths between reader and tag, including the reflection from all obstacles. The algorithm is more effective than the ordinary method with the complexity in calculation is reduced very much. The 3-dimension co-ordinate and radiation pattern of antenna are also included. This is the new idea when other studies pay a little or simple consideration on antenna radiation pattern. Then this analytical model is applied to one example of stored yard of containers. The simulation model shows the ability to estimate the performance of communication to retrieve many properties of the system.

4.2 Future work

On the case of using magneto-dielectric material, due to the difficulties and the high cost in making the material, this design temporarily stops at an idea design.

On the case of communication modeling for RFID system, this is a very interesting issue, and needs to develop more. In this thesis, this problem is just solved in channel modeling only. It is required to analyse whole the system and find the effect of other factors to the identification performance of RFID system. It is also required some suitable measurement results to verify the conclusions from simulation.

Moreover, this thesis just solves two of four problems before building the completed real active RFID system. Next step, two remaining problems, i.e. design of reader antenna and building of the reader will be conducted to form an fully RFID system.

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Busan, July 2006

Tran Viet Hong