Chapter 1

Introduction to Chipless RFID Tags

1.1 RFID Tags

Radio Frequency Identification (RFID) technology has become one of the most advanced and rapidly growing technologies that has the potential to make great economic progress for many industries. RFID replaces barcode due to its large data carrying capacity, flexibility in its working, and versatility in application. More recent advancements in IC technology are making RFID practical for new applications, such as consumer item level tagging, supply chain management, inventory control, and logistics. The technology can be considered as the future of identification and it has the potential to replace all products that are identified by a number or barcode till date. The cost of the tag is a hindrance for mass deployment of RFID tags for item tagging. Application Specific Integrated Circuit (ASIC) is the main component of RFID tag and this is the reason for the increase in the cost of RFID tags.

Radio Frequency Identification (RFID) is a wireless data capturing technique using electromagnetic waves which are utilized for automatic tracking and identification. RFID is very similar to bar code technology, but it uses radio frequency waves to capture data from tags, rather than laser for the bar codes on a label. The data carrying devices are called RFID Tags or Transponders. Sometimes they are called inlays, which is technically a tag mounted on a substrate that is ready to be converted into a smart label which
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contains a transmitting antenna, a receiving antenna and a data storing element such as integrated circuit chip. Sensors can be coupled with a tag to detect the surrounding environmental conditions such as pressure, temperature, the presence of a gas, moisture contents, and location. A reader typically referred to as an RFID interrogator is basically a radio frequency transceiver, that sends the interrogation signals to an RFID tag, which is to be identified. Firmware maintains the interface between the software protocol needed to encode and decode the identification data from the reader and the mainframe or personal computer.

1.2 RFID Applications

RFID has a variety of applications in industrial field where identification is needed. By affixing RFID to an object we can use and manage it to track goods, persons, animals etc. [? , ? , ? , ? , ? , ? , ? , ? , ? , ? , ? , ? , ? , ? , ? , ?]. RFID can be affixed to vehicles, electronic gadgets, books etc. We can use RFID to wirelessly identify something beyond line of sight operations. It stores a small amount of information and can change the information dynamically. The data can be altered during categorization or processing. It can communicate without human intervention and see an object from far away in the case of UHF RFID. In punitive atmospheres with severe filth, dust, moisture and excessive temperature conditions, it will work commendably without failure.

American armed forces used RFID in World War II (1948) to discriminate between friend or enemy aircraft and tanks. The enhanced versions of these systems are still used in defense fields. Years later from World War II the modules of the system were further technologically advanced and applications enhanced. The 1960s were the stage of premature explorations of RFID technology and laboratory experiments. In the early stage of 1970’s developers, researchers, corporations, academic institutions and government laboratories were enthusiastically working on RFID and prominent advances were being made at research laboratories and academic institutions like Los Alamos Scientific Laboratory, Northwestern University and the Microwave Institute Foundation in Sweden. During the mid-1970’s, large companies such as Raytheons Ray tag and Richard Klensch of RCA were also developing the technology. The development signaled the creation of practical, entirely
passive tags with an operational range of tens of meters. Illustrations of animal tagging examples with microwave systems are available at Los Alamos, Identronix and the inductive systems Europe. After the electronic article surveillance appeared, on the market, it was the first large-scale system of this kind.

In 1980’s RFID reached commercial applications i.e, it was the decade of full implementation of RFID technology. In U.S. it was extensively used for transportation and personal access purposes. In Europe the greatest attentions were for short range systems for animals, engineering and commercial applications. Toll roads in Italy, France, Spain, Portugal and Norway were fortified with RFID. Vital to the rapid development of RFID applications was the development of personal computer that permitted, suitable and economical collection and management of data from these systems. 1990’s were a significant epoch for RFID i.e, the development of standards. It was widely set up and became a part of daily life. Both inductive and microwave technologies were employed which discovered a wide variety of other applications in commerce. Companies such as Microdesign, CGA, Alcatel, Bosch and Philips were among them. At the end of the 20th century RFID was used not only for the electronic toll collection but also for parking lot access, fare collection, gated public access, campus access, as implants for animal identification and as an electronic immobilizer. The 21st century opened immense area of applications such as access / security cards, tracking, management, transactions, ticketing, labeling, logistics and distribution etc., with the smallest RFID tags.

1.3 RFID Classifications

RFID systems are commonly categorized, or differentiated, in one or more of the following ways, which includes describing the differences, advantages and disadvantages of the different types of tags that are commercially available. The following topics are covered in detail in this chapter.

- How RFID tag is powered
- Frequency of operation
- With or without an electronic chip
1.3.1 How RFID Tag is Powered

The tag requires power for communicating information to the reader through the antenna. Based on the way the RFID tags are powered, they can be classified as passive tags, semi-passive tags and active tags. Each type of tag has its own advantages and disadvantages that should be carefully considered when designing an RFID system.

Passive RFID Tags

Passive RFID tags are excited by the RFID reader. To power the tag circuitry, the tag relies on electromagnetic power obtained from the RFID reader antenna. Since the passive tags do not have their own power sources, the designs can be simple and inexpensive. Passive tags should be in close proximity to the reader antenna in order to obtain sufficient power to transmit a signal. The advantages of passive RFID Tag include:

- Less expensive
- Compact sizes
- Greater operational life
- Environmental robustness

Nowadays, very small size RFID tag approximately the size of a rice grain is used for different applications. The small size of passive tags also means that they are thin and very light. The compact size of RFID allows great flexibility in applications like animal tracking and individual sports competitions. Greater operational life is achieved by the lack of an internal power source. Since no internal power source is necessary, the tag cannot become nonoperational due to battery depletion. In contrast, active tags must have their batteries replaced every three to four years, depending on the exact nature of usage. Passive tags can last for decades, depending on how they are treated. Since passive RFID tags do not have a provision for a battery, they may be hermetically sealed during manufacturing. So this makes passive RFID tags inherently environmentally robust. Since the tag is sealed, moisture cannot enter the tag.

The disadvantages of passive RFID Tag are
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• Lower range

• Lesser Identification capability

• Low efficiency

The disadvantage of all kinds of passive tags is their extremely limited range. The lower range capabilities of passive tags have both advantage and disadvantage. From a blessing standpoint, the reduced range is advantageous for privacy reasons. The downside to lesser range is that a passive RFID system is much more sensitive to bad reads. The system must ensure that the tag is in closer proximity to the RFID reader antenna. A second major drawback of passive tags is their low identification capability.

Active RFID Tags

When compared to passive tags, active tags contain an on-board power source. It is usually in the form of a small power source, which powers both the tag’s on-board antenna and internal circuitry.

These tags conserve battery power by normally existing in a sleep mode. The tag wakes up or is activated upon entrance into an RFID system interrogation zone. When the tag is powered it provides data to the RFID system as requested. The operational life of an active tag can be lengthened when it can be put in a sleep mode while not in use. The length of the battery life is dependent on the time the tag is activated. The existence of an internal power source yields both advantages and disadvantages to the RFID system designer. The major advantages are greater range and greater identification capability. The disadvantages are more expensive, lesser operational life and large physical size.

Semi-passive RFID Tags

RFID tags can also be designed with features found in both passive and active tags. These techniques are implemented to retain the advantages while eliminating the disadvantages of each type. These tags typically use an internal battery to power the circuits that are internal to the tag. Usually, circuitry on semi-active tags includes sensors for monitoring environmental conditions.
such as humidity and temperature. When compared to active tags, the semi-active tag does not use its internal power source to communicate with the antenna. In the field of communications, this tag relies on electromagnetic field power received from the system’s antenna. By preserving its internal power in this manner we can greatly extend the internal battery life.

1.3.2 Chip RFID and Chipless RFID

Chip RFID tag contains integrated circuits to store unique identification code. Chip RFID is further classified on the basis of how it is powered, whether the memory is re-writable or not, writing capabilities and frequency of operation. Due to the use of the silicon chip, the tag is more expensive than the other identification method.

Chipless RFID tag is less expensive due to the absence of power source and silicon microchip. Most chipless RFID systems use the electromagnetic properties of various designs of conductor layouts/shapes and/or materials to achieve particular electromagnetic properties/behavior. The major challenge in designing a chipless RFID tag is how to encode data, without the presence of a memory chip. To overcome this problem, two general types of RFID tags can be identified: Time Domain Reflectometry (TDR) based and spectral (frequency) signature-based chipless RFID tags. There have been some reported chipless RFID tag developments in recent years. The main focus of this thesis will be on chipless RFID systems.

The low cost chipless RFID has the potential to provide low cost item tagging and thus replace the optical barcode from markets. The solution is to make the tag chipless and printable on low cost substrate such as plastics and papers, realizing that the chipless RFID technology is the only way of competing with existing tagging technologies. Depending on the technology used chipless RFID tag classified into two types

1. Spectral Signature Based Chipless Tags

2. Time Domain Reflectometry Based Chipless Tags

Different types of spectral signature based chipless tags is overviewed in the next chapter. The following section gives a brief discussion of Time domain reflectometry based chipless tags.
1.3.3 Time Domain Reflectometry Based Chipless Tags

Time Domain Reflectometry (TDR) is a microwave measurement technique to evaluate the time domain response of any electromagnetic system. TDR is used to determine all the effects of the system, including geometry and electrical properties by observing the reflected waveform. Various chipless RFID tags have been reported using TDR-based technology for data encoding. Such tags are interrogated by sending a signal from the reader in the form of a pulse and observing the echoes of the pulse sent by the tag. A train of pulses is thereby generated, which can be used to encode data. Two different types of TDRs based tags are available in market. They are:

1. Surface acoustic wave tag
2. Delay line based tag

Surface acoustic wave tag

Surface Acoustic Wave (SAW) tag was first developed by RFSAW Inc., [?]. SAW tags are based on the piezoelectric effect and on the surface related dispersion of acoustic(elastic) waves at low speed. If a crystal is elastically deformed in a certain direction, surface charges will be produced and hence electric voltages are developed. Conversely, the application of a surface charge to a crystal leads to an elastic deformation in the crystal grid. Usually Surface acoustic wave devices are operated at microwave frequencies, normally at ISM bands.

Surface acoustic wave transducers are used for wireless label system [?, ?]. The system consists of a pulsed transmitter, time gated receiver, phase detector and surface acoustic wave tag. SAW tag consists of interdigital electro-acoustic transducers and reflectors fabricated on piezoelectric substrates such as Lithium niobate (\(LiNbO_3\)) or lithium tantalate using planar electrode structures. The interdigital transducer is positioned at the end of a long piezoelectrical substrate, and a suitable dipole antenna operating at the required frequency is attached to its busbar. The interdigital transducer is used to convert electrical signals to acoustic surface waves and vice versa.

A high frequency pulse generated by the reader is send through its transmitting antenna. The dipole antenna of the transponder receives this interrogating signal, is supplied to the interdigital transducer and it converts the RF
signal into an acoustic surface wave, which flows through the substrate along the longitudinal direction. The frequency of the surface wave corresponds to the carrier frequency of the sampling pulse. The carrier frequency of the reflected and returned pulse sequence thus corresponds with the transmission frequency of the sampling pulse. A part of the surface wave is reflected by the reflective strips distributed across the substrate, while the remaining part of the surface wave travel to the end of the substrate and is absorbed there. The reflected parts of the wave travel back to the interdigital transducer, where they are converted into a high frequency pulse sequence and are radiated by the dipole antenna. This pulse sequence can be received by the reader. The number of pulses received corresponds with the number of reflective strips on the substrate as depicted in Figure 1.1. Likewise, the delay between the individual pulses is proportional to the spatial distance between the reflector strips on the substrate. The spatial layout of the reflector strips can represent a binary sequence of digits. Due to the slow speed of the surface waves on the substrate the first response pulse is only received by the reader after a dead time of around 1.5ms relative to the transmission of the scanning pulse. This gives decisive advantages for the reception of the pulse. The data storage capacity and data transfer speed of a surface wave transponder depend upon
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Figure 1.2: (a) Transmission delay line based ID generation circuit (b) Schematic diagram of transmission delay line based ID generation circuit (c) Binary code generation by the superimposition of delayed signals and (d) Input and output waveforms of the ID (Courtesy: Aravind Chamarti) [7]

the size of the substrate and the realizable minimum distance between the conducting strips on the substrate.

Delay line based tag

Transmission delay line based ID generation circuit is presented for Radio Frequency Identification (RFID) [7, 8, 9, 10, 11, 12]. The concept of binary code generation by the superimposition of the delayed signals is illustrated [7] and depicted in Figure 1.2. Obtainable delays, dependent on the frequency of operation, the length of the delay line and such circuits are sufficient for ID generation. This circuit receives the input signal from the antenna, generates the ID code, and sends the generated code back to the antenna.
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1.4 Motivation of Thesis

Nowadays the barcode is being replaced by RFID tag. The cost of existing RFID tag is much higher than the price of barcode. In order to lowering the price of RFID tag, we have to do research in it. So the primary aim of the project is develop a fully printable chipless RFID tag for low cost item tagging.

Spectral signature based chipless RFID tag requires compact, narrow band, planar multiresonator circuit. The multiresonator is an essential component of all types of spectral signatures based chipless tag. Hence the thesis is completely focused on multiresonator circuits with a narrow band. The bistatic radar principle or monostatic radar principle is used for reading the spectral signature based tag \[?, ?, ?\]. Depending on the technology, which is used by the reader the tag may consist of transmitting and receiving antennas, i.e, the spectral signature scattering based tag consists of multiresonators \[?, ?, ?\].

Preradovic et. al. presented a reading technique used for demonstrating the multiresonator circuit for chipless tag applications \[?\]. In this method the tag consists of two orthogonally polarized antennas connected with multiresonator. The multiresonating circuit modulates the interrogation signal and re-transmits to the reader through transmitting antenna.

The cascade spiral resonators and C-shaped resonators have low surface code density(\(bit/cm^2\)) \[?, ?, ?, ?\]. Here some techniques are proposed for improving compactness and quality factor with high surface code density. The different kinds of multiresonators such as coupled bunch hair pin resonator, open stub in the bifurcated transmission line and loop resonators on bifurcated transmission line shorted with via are discussed in the following chapters.

1.5 Thesis Organization

The thesis is organized as follows: Chapter 1: Introduction, The chapter gives a brief discussion of RFID tag applications and classifications.

Chapter 2: Literature Survey: This chapter presents a comprehensive review of available chipless RFID tags on the market and reported in the literature. Different types of chipless RFID tags based on different encoding techniques are reviewed with illustrations. Even though the technology is still
in its infancy, a number of developments have already been made in the industry, which are overviewed here. A comprehensive overview of the operating principle of spectral signature based chipless RFID systems is presented, followed by a description of different reading techniques used in the chipless tag reader. This chapter also covers a brief description of different types of planar resonators.

Chapter 3: Coupled bunch Hairpin Resonator Based Chipless Tag: A novel idea of coupled bunch hair pin resonator is introduced for realizing multiple resonances. Here a thorough study of parallel coupled line resonator, couple hairpin resonator and disc loaded monopole are carried out. Parametric studies and optimization of coupled bunch hair pin resonator is explained. It is noted that each resonance can be independently controlled by varying the length of the corresponding resonator and optimization of multiresonating circuit which is used for multiple bit data encoding. Finally, the chipless RFID tag using coupled bunch multiresonator is realized.

Chapter 4: Open Stub and Open Loop Multiresonator Based Chipless RFID Tag: This chapter explains the open stub and open loop multiple resonators placed in a bifurcated transmission line for creating multiple resonances. The chapter also describes the advantages and disadvantages of the same along with all the parametric studies and bistatic measurement results.

Chapter 5: Closed Loop Multi-resonator Based Chipless RFID Tag: The closed loop multiresonators placed in the bifurcated transmission line for creating multiple resonances is reported in this chapter. The theory behind closed loop multi resonator and its bistatic measurement results are also discussed.

Chapter 6: Conclusions and future scope of work: All the relevant points about the present research are concluded in the thesis with the insight to future studies. The thesis also includes the bibliography and a list of publications by the author in the related field.

REFERENCES

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