

# Radio Frequency Identification

*V Rajaraman*

**Radio Frequency Identification (RFID) has been around since early 2000. Its use has currently become commonplace as the cost of RFID tags has rapidly decreased. RFID tags have also become more ‘intelligent’ with the incorporation of processors and sensors in them. They are widely used now in many innovative ways. RFIDs are an integral part of Internet of Things (IOT) and IT systems of smart cities. In this article, we introduce the technology used by RFID systems, illustrate their use in several applications, and discuss problems of privacy and security when they are used.**

## Introduction

When a friend of mine visited me recently, I observed a dark disk stuck to the windshield of his car. I was curious and asked him what it was. He said it was a Radio Frequency IDentification (RFID) tag issued by the gated enclave he is residing in Bangalore. It is used to automatically open the gate of the enclave when his car approaches it from outside or when he leaves the enclave. When I bought a car recently, I saw an RFID tag stuck to the windshield which warned me not to remove it as it stored the car’s ‘horoscope’. My department issued an identity card that is also to be used as a contactless key to enter the building by taking the card near a box fixed to the door. The card has an embedded RFID tag. After demonetization, the National Highways Authority of India is mandating RFID tags in all trucks that use tolled highways regularly to eliminate dealing in cash and reducing queue formation at highway toll gates. I had read about RFID tags in early 2003 when it was being introduced but not widely used. In a decade, it has become ubiquitous. I wondered why and it dawned on me that with advances in semiconductor technology, RFID-based systems have now become cost-effective. We will



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## Keywords

Radio Frequency Identification systems, RFID tags, applications of RFID, privacy and security issues.



We will soon encounter many RFID systems in our daily lives. There will be many innovative applications of RFID systems in designing scientific experiments.

soon encounter many of them in our daily lives, and there will be many novel applications in designing scientific experiments. The purpose of this article is to explain RFID technology and their numerous applications.

### History of RFID

The idea of remotely identifying objects using radio signals is not new. The first use of radio-based identification occurred during World War II when most bombing missions took place at night. Bombers based in U.K. bombed German cities and Germans sent their bombers to bomb U.K. cities. Ground-based anti-aircraft guns and fighter planes had to distinguish between German bombers coming in to bomb U.K. and the Allied bombers returning after bombing missions. ‘Identification of Friend or Foe’ (IFF) was done by embedding a transponder (an abbreviation of transmit responder) on the wings of the bombers. Radar beams reflected from the Allied bombers’ transponders carried a unique identification which was used to recognize them. This technology of remote identification using radio waves did not find any civilian use till the 70s as they were bulky and expensive. They became cost-effective only when semiconductor technology matured. We give a brief history of RFID in *Table 1*.

### RFID Technology

RFID system consists of three parts: an RFID reader, an RF antenna, and an RFID tag (see *Figure 1*). The reader has four main parts: a power source, a radio frequency generator, circuits to amplify, digitize, and store the analog signal received from the tag, and a rudimentary microprocessor to process the data in the memory. This microprocessor is connected to an external computer. A radio frequency antenna is connected to the reader and transmits radio, i.e., wireless signals to a tag. This antenna also receives radio signals reflected by a tag’s antenna in response. A radio frequency tag consists of three parts: an antenna which receives radio signals from a reader, a rectifier which converts the

RFID system consists of three parts: an RFID reader, an RF antenna, and an RFID tag.



received signal to provide power to the tag, a memory in which the data to be used by an application is stored, and an optional simple processor (see *Figure 2* for the photograph of a tag).

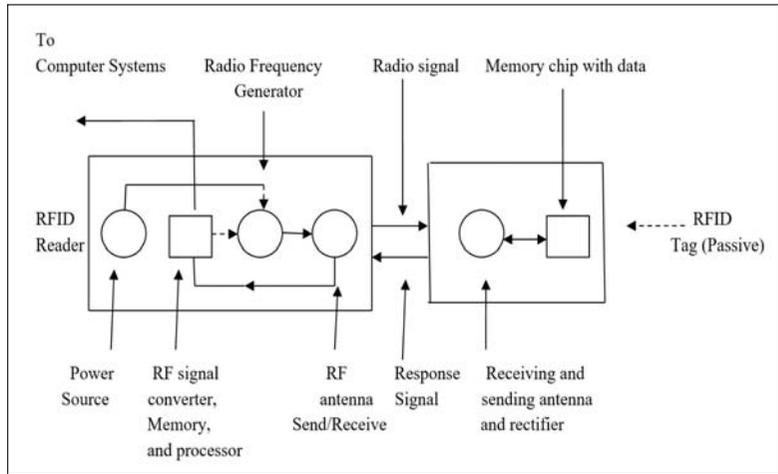
The above description is that of the simplest system using what is known as a ‘passive tag’. It is called passive as the tag has no internal power source. An antenna in the tag receives radio signals sent by the reader. This signal generates minute power (a few microwatts) that is sufficient to read the data from the semiconductor memory in the tag that stores a few hundred bits needed by an application. It also powers a simple low power processor which is used in some cases to encrypt the data in the tag’s memory. The data read modulates the tag antenna’s impedance which is sensed

**Table 1.** Timeline of RFID Applications.

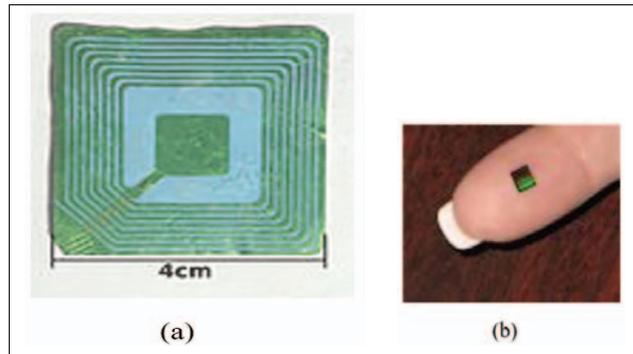
Year	Event
1942	Transponder in a bomber responds with a unique identity when interrogated by a radio beam. Used to identify friend or foe
1948	Stockman predicted the use of radio signals reflected from objects to identify them.
1971	Passive radio transponder with 16-bit memory, powered by interrogating radio signal invented by Cardillo.
1973	Use of 915 MHz signals to interrogate an RFID tag demonstrated. Both passive and active RFID tags and portable reader used.
1983	Patent granted for an RFID tag design.
2003	Walmart, a big retail store chain in U.S.A., and the U.S. Department of Defence mandate all major suppliers to put RFID tags in items supplied to them. ISO standardises low-frequency (120–150 kHz) RFID tags for animal identification and data collection. It initiates standardising RFID systems (ISO 18000 series of standards) for various applications.
2004	Food and Drug Administration (U.S.A) approves implanting RFID tags in humans and the use of m-chip cryptography for privacy.



**Figure 1.** An RFID system with a reader and a tag.



**Figure 2.** (a) Photograph of an RFID tag. The solid square part in the middle is a chip. It is connected to the antenna surrounding it. This is a large near-field tag. The electronic circuits are protected by plastic lamination. (b) Picture of one of the smallest tags.



by the reader’s antenna, filtered, converted into a digital form and sent to its memory, and processor. From this basic description, a number of questions arise about RFID technology. They are:

1. How close should the tag be to the reader for satisfactory reading of the data stored in the tag’s memory?
2. What type of data is stored in a tag’s memory?
3. What radio frequencies should be used by the RFID reader?
4. What type of antenna is appropriate for the RFID reader and the tag?
5. How is data stored initially in the tag’s memory?



6. Is it possible to write new data in the RFID tag's memory and erase old data?
7. Can a processor be integrated with the memory in a tag?
8. As the tag has no internal power source, how does it restrict its use? Is it possible to put a power source in the tag? What are the advantages and disadvantages of putting a power source in a tag?
9. Are there any restrictions on the environment in which RFID tags can be used?
10. Can an RFID reader read data from several tags in its vicinity? If yes, how?

The answers to these questions lead us to a large variety of readers and tags that are currently in use, different types of applications where RFID tags are used, and cost/benefit analysis of different types of tags. There are four different types of RFID tags and matching readers. We describe them in what follows.

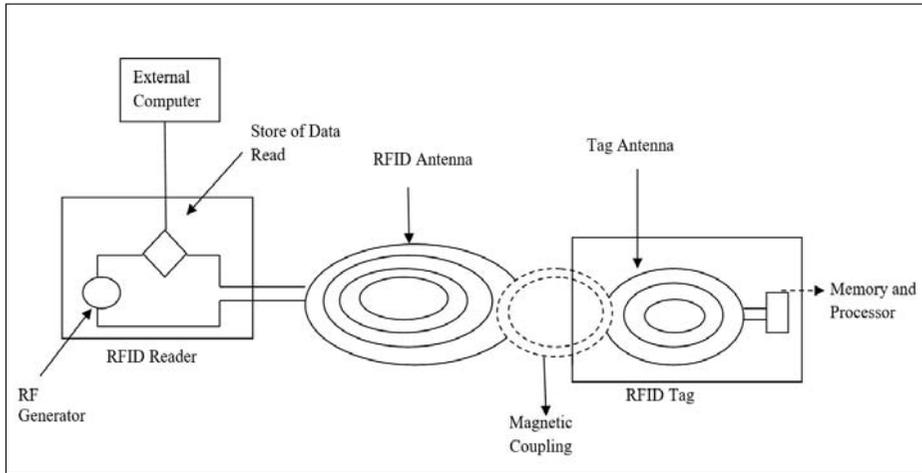
### 1. *Near-Field RFID Tag and Reader*

In a near-field passive RFID tag (see *Figure 3*) the antenna is a copper coil. A near-field RFID reader's antenna is also a copper coil. When a tag is taken close to a reader, the RF signal passing through the reader's antenna coil induces a current in the tag's antenna coil. The action is very similar to the way current is induced in the secondary coil of a transformer when a current passes through its primary coil. The coupling, in this case, is inductive coupling (often called magnetic coupling by vendors of tags) and the current induced in the tag's coil appears as a voltage across it.

The magnetic field induced by the reader's antenna coil is proportional to  $(c/2\pi f)$  where  $c$  is the speed of light and  $f$  the frequency. Thus as  $f$  increases, the induced voltage in the tag's antenna coil will reduce. Thus the near field tags can be used only with low frequencies of the order of a few hundreds of kHz to a few MHz. The magnetic field also reduces as the separation between the

There are four different types of RFID tags and matching readers. These are near-field and far-field RFID tag and reader, semi-passive tags, and active tags.





**Figure 3.** Near-field RFID reader, antenna, and tag.

tag and the reader increases. The induced field is proportional to  $(1/d^3)$  where  $d$  is the distance between the reader's antenna and the tag's antenna. Thus  $d$  has to be quite small. The order of magnitude of  $d$  is less than 20 cms. The frequency used by a low-frequency (LF) tag is typically 125 kHz, and a high-frequency (HF) tag is 13.56 MHz. HF tags are smaller than LF tags. Their range is also larger than LF tags. HF tags are typically used to tag small size items such as jewels and insects where small size and longer read range is required. LF tags are larger and are used in key cards in hotels, and ID cards where a larger size can be used, and distance from the reader is usually a few cms. They can also be used on wet surfaces. There are ISO standards for LF and HF near-field tags and readers.

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bands are used in ‘near-field RFID’ whereas UHF and microwave frequencies are used in ‘far-field RFID’.

The main advantage of near-field (NF) tags is the low cost of tags and readers. Near-field tags cost around Rs.10 if bought in large quantities (> 1000 tags). Readers cost around Rs.1000. The main disadvantage of NF tags is the requirement of the tags to be close to the reader.

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## 2. Far-Field RFID Tags and Reader

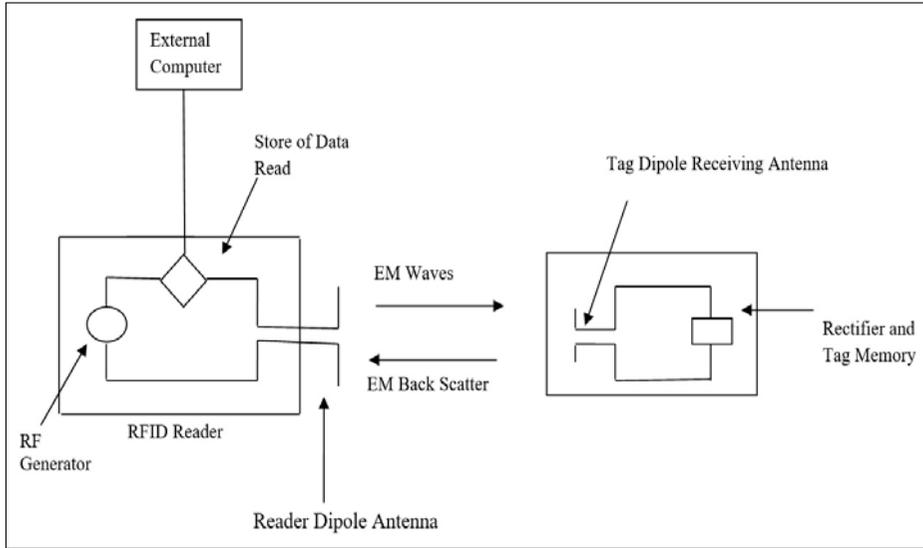
In far-field (FF) RFID systems (see *Figure 4*), a reader transmits radio frequency signals using a dipole antenna. The frequencies used are in the UHF (860–930 MHz) or the microwave band (2.45 GHz). The electro-magnetic waves transmitted by the reader antenna is picked up by the dipole antenna in a tag. This generates miniscule power (few microwatts) to power the memory and processor (if any) in the tag. The data in the memory varies the amplitude of the electromagnetic wave reflected by the tag’s antenna by a phenomenon called ‘backscattering’. This reflected signal is picked up by the reader’s antenna, converted into digital form, and stored in its memory. The range of far-field systems depends on the amount of power received by the tag’s antenna and the sensitivity of the reader’s antenna to receive minute backscattered waves. The attenuation of electromagnetic waves through air medium is proportional to  $(1/d^2)$  where  $d$  is the distance between the reader’s antenna and the tag antenna. The energy of the backscattered signal is thus proportional to  $(1/d^4)$ . Due to better design of readers and tags of FF RFID, the distance between the reader and the tag can be up to tens of metres.

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## 3. Semi-Passive Tags

The tags we described so far are called ‘passive tags’ as they have no source of power and depend on the power picked up by them from the reader. As this is only a few microwatts, these types of tags have two limitations. They are:





**Figure 4.** Far-field RFID reader, antenna, and tag.

(i) Besides a memory to store the identity of the tag, only a simple processor can be powered.

(ii) The tag’s antenna sends data stored in the tag using only the power harvested from the reader. It does not have a power of its own. Thus the distance between the tag and the reader is restricted to few cms in LF and HF tags and less than 50 metres for UHF tags.

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The major advantage of a passive tag is its long (almost indefinite) life, as there is no battery to recharge or replace. It is also low cost. In semi-passive tags, a low capacity battery is integrated in the tag. It is used only to power the processor in the tag. The power is not used by the tag’s antenna to transmit contents of the tag’s memory to the reader. Semi-passive tags thus do not increase the range of readers. However as additional power is available, electronic sensor circuits can be added to the tag and the processor in the tag can be more powerful. A tag with a temperature sensor attached to a drug bottle can continuously monitor the temperature of the drug during transit and store it in the tag’s memory. If the temperature exceeds a set limit the drug would be rejected. As the battery has to supply very low energy its life is



quite long.

#### 4. Active Tags

In active tags a battery is used to power both the integrated circuit in the tag and also transmit electromagnetic waves to a reader. It does not depend upon the power harvested from a reader for its operation. A reader can thus be inexpensive. The major advantage of an active tag is its long range. The contents of an active tag's memory can be read from a few hundred metres from a reader. An active tag can send information periodically to a reader if an application requires it. The major disadvantages of active tags are their high cost due to the battery and their shorter life. The tag has to be discarded when the battery is discharged unless it can be wirelessly charged. There are attempts to use solar powered batteries. But such tags have limited applications.

In *Table 2* we summarise the classification of RFID systems

#### Storing Data in RFID Tags

Normally data to identify an object is stored in a read only memory in tags. If the object tagged is a product, standard identification codes have been evolved by Electronic Product Code Global (EPC Global, a standards organization). It is a 96-bits code with 8-bits header, 28-bits manufacturer code, 24-bits product type code, and 36-bits unique ID of the item. Thus it can encode 16 million product types, and 64 billion unique IDs for products – an enormous number. The header includes bits for error detection. Depending on the application, codes other than product codes may be used, for example, ID for people, animals, tickets, etc. The larger the storage the higher will be the power required by the memory chip in a tag. Thus the number of bits stored is optimized for applications. Up to 1 Kbits are stored in tags.

Data may be stored permanently in the memory of tags at the time of manufacture of tags. They may be just serial numbers,

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<b>Frequency Band of Reader</b>	LF 125--135 kHz	HF 13.56 MHz	UHF** 860--930 MHz	Microwave 2.45 GHz
<b>Reader to Tag Communication</b>	Inductive coupling. Near-field	Inductive coupling. Near-field	Electromagnetic backscatter. Far-field	Electromagnetic backscatter. Far-field
<b>Approximate Range* (distance between tag and reader)</b>	< 25 cm (Longer range with bigger tags)	Passive < 1m Semi passive < 25 m	Passive < 50 m Active < 200 m	Passive < 20m Active < 200 m
<b>Antennas in Tag and Reader</b>	Coil	Coil	Dipole	Dipole
<b>Ability to Read Near Metal/Wet Surface</b>	Good	Fair	Poor	Bad
<b>Data Transfer Rates</b>	< 10 Kbps	< 100 Kbps	< 100 Kbps	< 200 Kbps
<b>Cost</b>	Low	Low	Medium	High
<b>Applications</b>	Animal tagging Access control Credit card Laundry tag Passport tag	Insect tagging Smart tickets Jewellery tags Car key Library book tag	Toll collection Asset tracking Inventory control Baggage handling	Toll collection Production line tracking Supply chain

\* Range of tags depend on many factors -- environment, power transmitted by reader antenna, type of ICs used in tags, passive, semi-passive or active tags, orientation of reader antennas with respect to tags (see [skyrfid.com/RFID-Tag\\_Read-Ranges](http://skyrfid.com/RFID-Tag_Read-Ranges) as a representative manufacturer's range information)

\*\* European/Indian standard 868--870MHz. US/Canada standard 902--928 MHz

**Table 2.** Classification of RFID Systems.

and when read in an application they are mapped by the reader to appropriate code in a back-end database. These type of tags are called ‘read-only tags’. It is also possible to store data in tags by a user once. For example, when an item with a tag is moving on a conveyer belt, a reader can write a product code and a unique



serial number in the memory of the tag attached to the item. This data is written only once. These tags are called ‘write-once tags’.

There may be applications where there may be a requirement to write, erase, and rewrite data in the memory of tags. Such tags are reusable and are called ‘read-write tags’. Read-write tags add flexibility to applications as data may be written or added in tags’ memory as items move through a supply chain. Data may be updated as required. Some applications may require data in the tag’s memory to be encrypted. Encryption is done by a processor in the tag. Decryption would be normally done by a back-end computer attached to the reader. To cater to privacy concerns, particularly in retail sales of expensive items, some tags have provision to disable them when an item leaves a store.

### RFID Tags with Sensors

Having sensors integrated inside an RFID tag is useful in many applications. If medicines or food items are transported in a cold storage system and require the temperature to be maintained within a certain specified range from the origin to the destination, a temperature sensor integrated in the tag may be used to periodically record the temperature. When delicate items are transported, they should not receive shocks due to acceleration beyond specified limits. This can be recorded by a force measurement sensor. Another parameter that may be measured and recorded by a sensor is humidity. As sensors require power, semi-passive tags are appropriate as they have a built-in battery. When sensor data is to be recorded at regular intervals, a built-in clock and enough memory to store the data over the required period is needed in a tag. When data from the tag is read at the destination, all this data is read by a reader, and computer attached to the reader would interpret the data and take appropriate action.

Readers must be able to distinguish between identity data and sensor data received from the tag. Sensor data is separately stored with its own distinct label. The computer attached to readers can

Data may be stored permanently in the memory of tags at the time of manufacture of tags. These type of tags are called ‘read-only’ tags. There are also ‘write-once’ tags and ‘read-write’ tags.

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### RFID Standards

A standard organization called EPC Global has formulated numerous standards which are usually adhered to by manufacturers globally. Frequency standards are governed by frequency allocation by the governments.

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### Examples of RFID Applications

There are enormous number of applications of RFID systems. Any application requiring accurate identification and tracking of items tagged with RFID tags can profit from the use of RFID, provided it is cost-effective. They are used in access control systems, retail stores, tracking systems (to track people, animals, birds, and insects), supply chains, logistics, and manufacturing. I have selected a representative set of applications.

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#### 1. Access Control to Buildings

There are two types of access control systems used to enter buildings. One of them is to permit authorized persons to enter buildings or rooms. The other is to combine access control with a system to record entry and exit time of employees into buildings. This may include a system to locate an employee if an organization has many buildings.

The system assumes that the entry point of each building has an RFID reader. Each employee is issued an RFID card embedded with a tag that stores the ID of the employee in its memory. (There



are also some organizations that issue a wristband to all employees with an RFID tag). When an employee takes the card near the reader, the reader reads the tag and sends the data read to a back-end computer which is connected to the reader. This computer has a database of authorized IDs of employees allowed into the building. If the employee is authorized, the computer sends a command to open the door latch, and the employee can enter the building. The entry time is also recorded in the database. If an authorized manager wants to find out where an employee is currently located, the database can be interrogated *via* a desktop computer connected to the database. The entry and exit time of employees can also be used for ensuring security. The RFID technology used in this case is usually a near-field system with a low-frequency RFID tag as the card or band has to be taken within a few cms of the reader at the entrance. Near-field tags are inexpensive and the card size can be about 4 cm × 3 cm.

## 2. *Contactless Entry to Metros with Prepaid E-tickets*

In many countries, smart tickets can be bought for travel by local trains/metros. These tickets have an RFID tag embedded in them. A passenger entering a station takes his or her ticket near an RFID reader at the entry gate. The tag in the ticket is read, and the ticket ID is compared with those stored in a database to authenticate the passenger and also to check whether there is sufficient balance in the prepaid ticket. If yes, the entry gate is opened. A message is also displayed warning if the balance in the prepaid ticket is low to allow the passenger to top up the ticket. These systems normally use near-field tags which are inexpensive as the application requires the tag to be taken near a reader.

An interesting example of such a system is the oyster card used by the London Underground trains, buses, and ferries as an integrated cashless commuter card. This card can be used in all modes of public transport in Greater London. The oyster card is taken near a yellow coloured RFID reader port at the entry turnstile of a station or near an RFID reader port at the entrance of a bus. The reader sends the tag ID to a central computer that au-

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Use of RFID embedded cards by transport systems eliminates cash collection and daily accounting. The data gathered by the computer may be used to optimize scheduling of local trains and buses.

thenticates it, finds if there is sufficient balance in the card, and stores the data. At the destination underground station, the passenger again takes the card near the reader at the exit gate. The reader calculates the fare based on the distance travelled, deducts it from the card and stores the ticket's ID and balance in its computer. In buses, there is no reader at the exit as buses charge a flat rate. Cash is not accepted in buses. Apart from the convenience of using the card on all modes of transport and eliminating cash collection and accounting daily, London commuter system uses the data gathered by the central computer to optimize scheduling of trains and buses. With millions of cards in use, the cost of an oyster card with an RFID tag is amortized by the fare collected. The system is a near-field system using low-frequency tags.

### ***3. Access Control to Gated Communities and Toll Roads***

Some high-end gated communities have an access control system for cars of residents. An RFID tag is stuck to the windshield of authorized resident's cars. The tag stores a unique coded ID. As a car approaches the gate, an RFID reader mounted on a pole few metres ahead of the gate reads the tag and sends its ID to a server connected to the reader. The server has a database of authorized IDs. If the ID read is authorized, the server sends a command to the gate control system to open the gate and the car can drive in. The entry time is recorded by the computer system. This type of application where a tag has to be read from a few metres while the car is in motion requires a far field tag that works in the UHF band. The tag costs a few hundred rupees.

A similar method is used for automatically allowing vehicles with prepaid RFID tags to enter toll roads. Special lanes are reserved for vehicles with tags. The toll is deducted from the tags' account stored in a server. A warning is displayed if the balance is below a preset value requesting the user to replenish the amount. UHF far-field tags are used.



#### 4. Retail Store Systems

Most supermarkets use barcode based systems to check out items purchased by customers. Each item has a printed barcode with its ID and price. At the checkout counter, the counter assistant scans each item with a handheld or a counter mounted scanner that sends the scanned data to a computer which retrieves the cost of each item scanned and prints an itemised bill. In a supermarket counter, queue builds up if a customer has a large number of items to be checked out. As each item is to be manually scanned, it takes time. Sometimes the printed tag is blurred in which case the automated system fails, and manual intervention is required. The major advantage of barcodes is that it costs almost nothing as many packaged goods come with preprinted barcodes. Instead of barcodes an RFID tag may be stuck to each item with data including ID, cost, expiry date, etc. stored in it. Each checkout counter has an RFID reader that reads the tags of all items in the cart. The counter assistant need not take out each item and scan it. It is possible to read all the tags simultaneously using a collision avoidance algorithm (see *Box 1*). Data read from the tags is sent to a computer which computes and prints an itemised bill. Check out is thus much faster and human errors are minimised.

Another advantage of using RFID tags on all items in the store is that it provides anti-theft protection. If a shoplifter walks out concealing an item without paying, a powerful reader mounted at the exit gate that can read tags from a distance will sound an alarm which will alert security.

The major disadvantage of this system is the cost of tags. Paper barcodes cost almost nothing. Near-field tags in quantities of ten thousands cost nearly Rs.10 per tag. Thus using such a system will not be feasible except for shops selling expensive items.

In India, clothing stores that sell expensive items such as silk saris and suits, and jewelers may use RFID tags mostly as an anti-theft device, and also to reduce human error in billing (sometimes intentional) by staff. Near-field tags will be appropriate.

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**Box 1. Reading Many Tags Simultaneously**

When many items with RFID tags are in the vicinity of a reader, all the tags will send their identity information simultaneously to the reader. An anti-collision algorithm has to be implemented in the reader to separate the IDs of the tags and store them. It should also be ensured that all the tags are read. There are several algorithms with their advantages and disadvantages. In the simplest algorithm, a tag responds with item ID when energised by the reader. It then waits for the reader to send an acknowledgement. The reader responds with a positive acknowledgement if the ID has been correctly received. If there is a collision with the ID sent by other tag(s), the reader sends a negative acknowledgement. All the tags stop responding and wait for different random intervals and resend their IDs. The probability of collision of IDs of different tags, in this case, is low. Once a tag's ID has been correctly interpreted by the reader, it sends a positive acknowledgement to the tag. The tag then remains silent. This process is repeated till all tags' IDs are read and all of them go silent which indicates that all tags have been read. In practice a few hundred tags can be read per second. The tags need to have, besides identity information, timers, and logic circuits to recognize acknowledgement sent by the reader, random back-off capability, and silent mode. As these additional logic circuits require power, semi-passive tags were used earlier. With advances in semiconductor technology, currently, specially designed passive tags can harvest enough power from readers to drive the additional logic circuits.

Most countries in the world have now put RFID tags in passports. The tag contains all the personal information, photograph, and biometric data.

Another advantage of using RFID systems in stores is that it enables locating items and eases inventory control. A handheld reader may be taken and shelves can be scanned to locate items and take the inventory of items in a store periodically. The computer based inventory control system will have a record of items stocked and sold giving the current inventory. Physical check may be necessary periodically to detect missing or misplaced items.

**5. Detecting Counterfeit Items**

Expensive branded products such a Louis Vuitton hand bags or Rolex watches are often counterfeited. To detect counterfeit, the manufacturers of such products nowadays stitch or stick an RFID tag inside the item. When a product is taken near a reader, it detects if an RFID tag with the authorized code is in the product and if so beeps. Fake products do not beep. This assures a customer that the item is genuine.



## 6. Use of RFID Tags in Passports and Documents

Important documents can be secured using RFID tags. Most countries in the world have now put RFID tags in passports. The tag contains all the information printed on the first two pages (name, address, etc.), photograph, and biometric data (fingerprints, iris scan). It is stored in the Read only Memory (ROM) of the tag. The tag is laminated and placed inside the back cover of the passport. In some countries, it is bound inside the passport in a laminated sheet. The tags are near-field tags. When a passenger presents his or her passport to immigration authorities, it is placed on top of the reader and the information in the passport is displayed on a computer screen attached to the reader. The passport data is also sent to a central computer.

When a passenger presents his or her passport to immigration authorities, it is placed on top of the reader and the information in the passport is displayed on a computer screen attached to the reader. The passport data is also sent to a central computer.

This system has several advantages. It assists the immigration officers' central computer to quickly check the authenticity of the passport and check if the person's name is on a list of undesirable aliens. If a passport is lost, it is not possible to forge it by changing the photograph as the photo is in the tag. A tag cannot be removed without destroying it as it is laminated and the memory chip is very delicate. The content of the memory is digitally signed by the issuing authority which is difficult to forge. Standards on the information stored in the tag, tag type, and digital signature have been approved by the International Civil Aviation Organization (ICAO). There was an apprehension that the contents can be read remotely leading to loss of privacy. Thus US passports have copper meshes inside the front and back covers that attenuate RF signals and prevent reading a tag from a distance. The passport has to be opened and the page with the tag in it has to be placed over the RFID reader. The use of tag increases the cost of a passport by about Rs.100. It is expected that passports issued in India will also have RFID tags that will adhere to the ICAO standard. A passport with RFID tag will have a symbol printed on the cover (see *Figure 5*).

Important documents such as land registration, will, and bonds can also have an RFID tag laminated to prevent forgery. Some



**Figure 5.** Symbol printed on a passport cover to indicate that it has an RFID tag inside.

As a part of the smart city initiative of the Government of India, public buses in major cities will be equipped with RFID tags and a global positioning device to assist in scheduling buses and also prevent over speeding. These tags will use far field tags in the UHF band.

countries are planning to incorporate RFID tags in high denomination currency notes. Reserve Bank of India considered embedding RFID tags in Rs.2000 notes to prevent counterfeiting but did not do it, as it is expensive.

### ***7. Car Anti-theft Systems***

Some automobiles are equipped with so-called intelligent computerised anti-theft system. The car key has an RFID tag with a unique factory-assigned code. It is read by a reader in an electronic control unit of the car which controls the ignition of the car. If a wrong key is used, the control unit will disable the ignition system. If you lose your key, you have to buy a new key from the dealer who sold you the car. The extra cost of having this security in a system is between Rs.1000 to 4000. These systems use UHF far-field tags.

It is reported in the press that Government of India will be amending the motor vehicles act to require all automobile manufactures to put RFID tags on the licence plate of vehicles that can be read by an authorised road transport officer. This will become part of the data in the registration certificate of a car which already has a microchip with details of the car. Use of RFID tags will track vehicles and act as a deterrent to vehicle thieves. As a part of the smart city initiative of the Government of India, public buses in major cities will be equipped with RFID tags and a global positioning device to assist in scheduling buses and also prevent over speeding. These tags will use far field tags in the UHF band.

### ***8. Transporting Ore from Mines***

Many mines such as coal and iron ore mines use RFID system to monitor the movement of ore from the pithead of mines to the stockyard.

Many mines such as coal and iron ore mines use RFID system to monitor the movement of ore from the pithead of mines to the stockyard. Ore is transported by thousands of trucks. Truck operators are paid based on the distance travelled and the net weight of the ore carried by each truck. It is useful to monitor if there is theft of ore during transit. At the mine pithead empty trucks arrive at an in-gate, are loaded, go over a weighing bridge, and leave through



an out-gate. An RFID tag is stuck to each truck's windshield. At the in-gate, an RFID reader records the truck ID and the empty weight of the truck in a back-end computer. The truck is then loaded and goes over a weigh bridge at the out-gate. An RFID reader reads the ID of the truck and records in the back-end computer the truck's ID, the loaded weight, and the date and time of departure. A slip with this data is printed and given to the driver. The back-end computer thus has the truck ID, empty weight of the truck, the loaded weight, ore weight, and the time of leaving. When a truck reaches the stockyard, it passes over a weight bridge and the truck ID is read from its tag, received weight, and arrival date and time are recorded in the back-end computer. A receipt is printed and given to the driver. The computer compares the weight of the ore loaded and received. Allowing for some standard spillage en-route, the computer determines using the truck ID the ore weight that should have been received to detect theft if any. Payment is calculated based on an agreed formula that uses the distance traveled, the weight of ore received, and the penalty for excess spillage. The system is needed as thousands of trucks from many contractors are employed. The computerised system is transparent and it prevents excessive delay in transit, and large-scale thefts en-route. Another advantage is quick payment of transport cost to the truck operators with minimal disputes. As the computer has all data the ore company can rate truck operators' performance and negotiate appropriate transport contracts. The RFID system uses far-field UHF tags.

### 9. *Weighing Birds*

In a biology experiment, a student had to weigh a group of birds over a period of time. An RFID tag with the bird's ID was attached to its feet by an adhesive. As the tag is very small it did not affect the birds' normal activities. The feed for the birds was kept near a platform with a load cell and an RFID reader. Each time a bird sat on the platform to feed, its ID was noted by the reader, its weight measured by the load cell, and sent to a computer connected to the reader and the load cell. The time was stamped by

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To modernise the scheduling of rolling stock, the Indian Railways plan to attach RFID tags to each passenger bogie, goods wagon, and engine.

the computer and the data stored in the computer. Thus over the period of the experiment, a log of birds' ID, their weight, and the number of times they fed was readily available from the computer's disk. In this example near-field high-frequency tags and corresponding readers are appropriate as the distance of the reader from the platform on which a bird sits is a few cms and HF tags are small and light.

### *10. Use of RFID System by Railways*

It is reported that in the 2016–17 Railway budget, a large allocation has been made by the Indian Railways to modernise the scheduling of rolling stock. Each goods wagon, engine, and passenger bogie will have a unique RFID tag affixed. Readers will be installed at appropriate places to read the tags of wagons, engines, etc., as they pass. (Chinese Rail System affixes the tag at the bottom of the wagon and a reader is installed between the rails to read tags). The RFID tag data of all rolling stock read by all the readers will be processed and sent to a centralised computer system. This will allow the centralised system to know where exactly an engine, wagon or a passenger bogie is at any given time. This massive data can be processed to efficiently use the rolling stock. Besides creating software to optimally schedule engines, bogies, wagons, etc., historical data can be used to reduce idle time of railway's rolling stock. The RFID technology, in this case, is far-field UHF system. As the tags have to be stuck to metal parts and as UHF gets attenuated, and have to be protected from poor environmental conditions, they must be enclosed in thick insulator boxes and screwed on to the side of wagons, engines, etc.

Many libraries are now using RFID systems to allow users to self-issue and return books, keep track of books in the library, prevent thefts, and generate a message to a user a day before books become due.

### *11. Application of RFIDs in Library*

Many libraries are now using RFID systems to allow users to self-issue and return books, keep track of books in the library, prevent thefts, and generate a message to a user a day before books become due. This is done by tagging each book in the library with a near-field low-cost RFID tag. Each member is also issued an ID



card with an RFID tag giving details of the member such as name, email id, address, mobile number, etc. When a member enters the library, his or her ID tag is read and checked if he or she is a legitimate member of the library. If not an alarm alerts the security staff. There are two counters, one to issue books and the other to return books. Each counter is equipped with an RFID reader. When a member wants to issue a book or books, he or she places the ID card on the reader followed by the book(s). The reader reads the ID of the member followed by data about the book(s). The reader appends the data on the issued book(s) and stores it in a database along with the due date for returning the book(s). SMS is also sent to the member giving the details of books issued and the due date. At the exit gate, a member has to pass through a security gate equipped with an RFID reader. It reads the ID information and tag information of books being taken out. Using this data, it checks whether the books are in the issued books database. If not it alerts security. When a member wants to return the book(s), he or she places his or her ID card and the books one by one on the reader in the return counter. The data read by the reader is used to delete from the issued books database of a member the books returned. The issued books database is scanned everyday, and email/SMS is sent to all members with details of books which are to be returned the next day. If a book is returned late by a member, fine is automatically deducted from the pre-paid deposit of the member. If the deposit is below a pre-assigned limit, a member is not allowed to take out any book.

Another advantage of the system is that it simplifies checking the books inventory in the library. A handheld reader can be periodically used by the library staff to scan all the shelves and register the books in a database. This along with the issued books database gives the current holding of the library. This system also enables the library to obtain a list of missing/misplaced books.

RFID systems used by large organisations such as railways, metros/bus systems, supply chains of large companies and similar organisations do not have a single RFID reader and tag system. They use many readers and tags often spread over a large geographical area.



## Complex RFID Systems

RFID systems used by large organisations such as railways, metros/bus systems, supply chains of large companies and similar organisations do not have a single RFID reader and tag system. They use many readers and tags often spread over a large geographical area. In single RFID reader, the reader has only hardware to convert the analog data received from the tag to digital data after filtering noise. For the data to be used in an application many more functions are needed. For example, the data in tags would normally use an error detecting or correcting code. Sometimes the data may be encrypted. In applications where multiple tags are read, duplicates (if any) has to be removed. These types of operations require more computing power usually not available in a reader. Thus, readers are attached to a computer that is programmed to perform these operations. The software in this computer is called the 'middleware'. The output of this computer is sent to a larger back-end computer which is used to run the necessary application program.

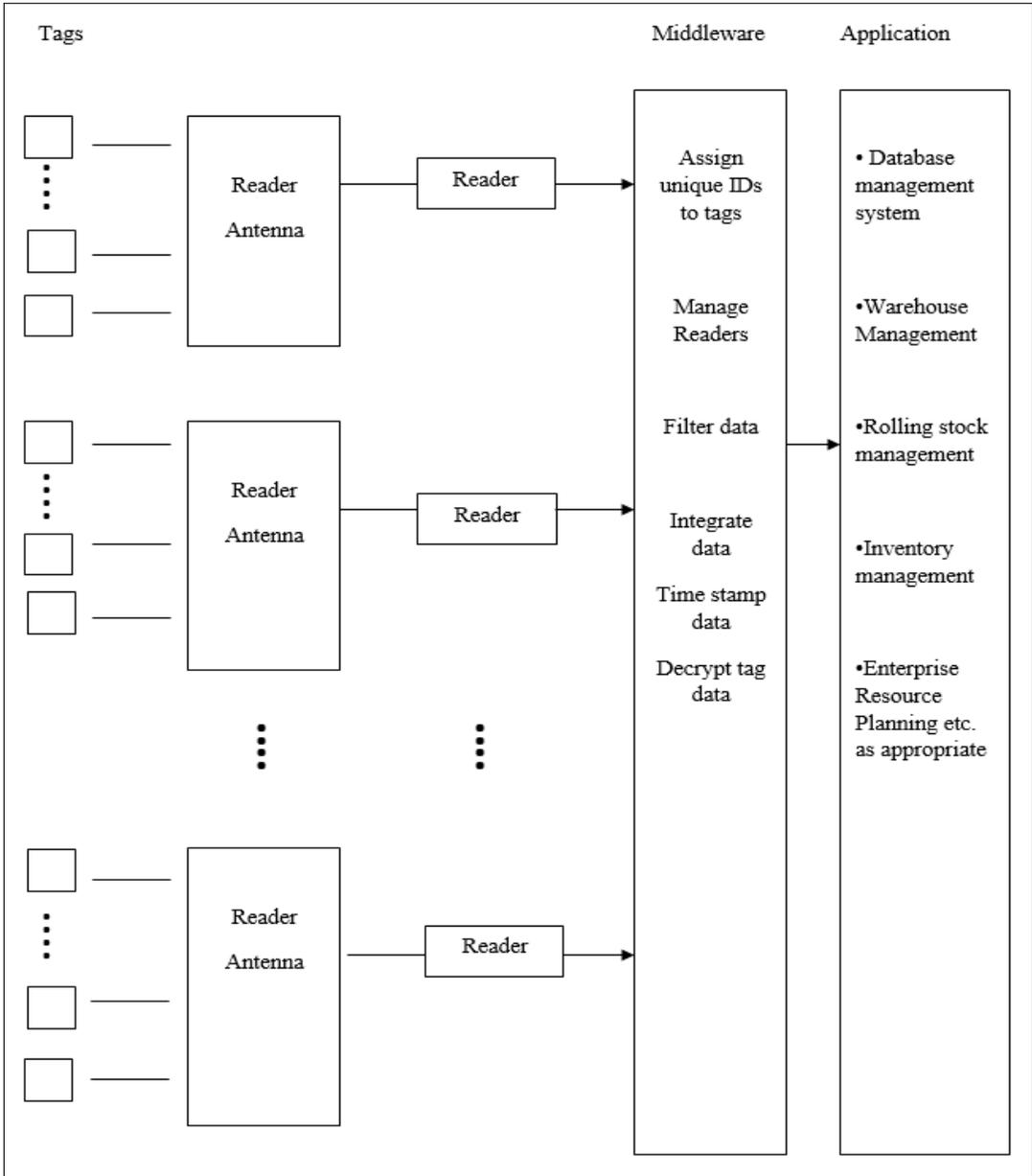
In many applications where a large number of readers and tags are used, the systems becomes quite complex. In *Figure 6* we show a complex RFID system. Observe the large number of tags and readers whose outputs have to be combined and used by an application. In such cases, the middleware has many functions that include:

- (i) Assign unique IDs to the tags from which data is read, and associate data with tags.
- ii) Manage the readers.
- (iii) Collect and integrate data from various readers.
- (iv) Filter duplicate data, time stamp data, decrypt data if required.

Thus, a typical RFID system used in industry will have besides tags, antennas, and readers, middleware and appropriate back-end application software that requires larger computers for their execution. The type of application may range from simple database

A typical RFID system used in industry will have besides tags, antennas, and readers, middleware and appropriate back-end application software that requires larger computers for their execution.





**Figure 6.** A Complex RFID system.

management system and associated querying to Enterprise Resource Planning (ERP), Inventory Management System and similar large application programs.



## RFID Privacy Issues

By privacy, we mean providing confidentiality to personal data. For example, people may not like others to know what they purchased, where they went using public transport, their personal data that is in a passport and similar information. Use of RFID tags by stores where customers purchase expensive items may lead to privacy risks. When they leave a store with items purchased, someone with a powerful RFID reader that can transmit high energy electromagnetic signals may be able to read the tags and know what a person purchased and their cost. Thus, privacy advocates have been concerned about the use of RFID tags by large stores. Use of RFID tags used in metro tickets, if read by unscrupulous individuals can reveal complete information on where a person travels regularly. Similarly, data in tags embedded in passports are also a potential threat to the privacy of individuals. Due to all these concerns, precautions have been taken by organisations deploying RFID systems. For instance, many stores disconnect the antenna in the tag after items are purchased using a tag disabling system. Some others physically detach the tags. The only problem with this is the difficulty a store will have when an item is returned to verify whether it is bought from their store. Tickets issued by metros, normally use near-field tags. The ticket has to be placed within a few cms of the reader. It is difficult for powerful readers to read near-field tags unless they come very close (a few cms) to a passenger. If tickets are stored in a metallic case after use, they cannot be read. Due to privacy concerns, most passports have tags placed inside the passport, and the covers of the passports have copper mesh inside the covers. The copper meshes will make it very difficult for a powerful reader to read the tag unless the passport is opened. In addition, the data in passports are encrypted, the key is separately stored, and needs a different reader.

It is desirable for organisations that collect information from RFID tags of users to anonymize them before they are stored in a back-end computers' database. In other words, personal identification details are omitted before the data is stored.

Apart from concerns about unscrupulous persons reading RFID tags, a more serious concern is the data stored in back-end computers by the stores when they scan customers' tags and by metros that have complete travel details of their passengers' travel in



their servers. The data is stored for analysis to improve their services but have a potential to be used improperly. It is desirable for organisations that collect information from RFID tags of users to anonymize them before they are stored in a back-end computers' database. In other words, personal identification details are omitted before the data is stored. Another solution is to encrypt the information related to user identity. All information technology uses, besides RFID, such as use of email, searches using search engines, and buying items online have potential privacy hazards. Many countries are enacting privacy laws to prevent unauthorised use of personal information that would include information obtained from RFID tags.

By security, we mean protecting RFID data from intentional destruction, disclosure, corruption, denial of service, and similar actions by unscrupulous individuals or organisations.

### **RFID Security**

By security, we mean protecting RFID data from intentional destruction, disclosure, corruption, denial of service, and similar actions by unscrupulous individuals or organisations. A competitor of a retail store may read the tags of customers clandestinely when they leave a store to get information on the preference of customers and use the data to optimize inventory in its own store.

An unscrupulous customer may access a tag and reduce the price of an expensive item. Another security risk is someone making duplicate tags illegally. For example, security experts were able to read RFID tags embedded in London Underground ticket, duplicate them, and top up any prepaid amount which demonstrated the security flaw in the tag. The tag was using simple encryption which hackers could decrypt and find the encryption key. London Underground ticket was made more secure using an RFID tag with AES encryption<sup>1</sup> that is difficult to decrypt. Use of AES encryption required a higher cost tag with more processing power.

<sup>1</sup>V Rajaraman, Cloud Computing, *Resonance*, Vol.19, No.3, p.250, 2014.

### ***Denial of Service***

Denial of service refers to jamming a reader by sending out high energy radio waves from transmitters in the vicinity of readers



Denial of service refers to jamming a reader by sending out high energy radio waves from transmitters in the vicinity of readers using the same frequency as that of the reader thereby denying service.

using the same frequency as that of the reader thereby denying service. Yet another attack by a vandal is to disrupt the connection between readers and the back-end computer resulting in a service breakdown.

### *Tracking*

While items with RFID tags are being transported, a competitor may use an RFID reader and read the data in the tags. If the tags are encrypted, the actual data may be difficult to gather. However, the number of items with tags will be easy to find and this may be useful to a competitor.

### *Attacks on Servers*

Servers that process information retrieved from tags are vulnerable to various attacks and data theft. This is not specific to RFID systems but is a problem in all IT systems and needs attention.

### **Conclusions**

RFID systems were first introduced for tagging consumer goods in early 2000. They got a boost when large stores required their suppliers to use RFID tags in addition to barcodes on items supplied to them. This gave a boost to the RFID industry. When an extensive use of RFID tags started, millions of tags were needed. This reduced the cost of tags. Simultaneously there was rapid development in the semiconductor chip manufacture with the proliferation of very low power processors. As the power available to tags is primarily harvested from readers, development of low power processors gave a boost to RFID tag industry. As of today, the use of RFID tags is proliferating due to rapid reduction in the cost of RFID tags. If the cost of tags is reduced to around Rs.5 there will be a surge in the use of RFID in consumer stores. As in many IT systems, RFID systems also lead to loss of privacy that requires attention. There are also security problems to be combated. RFID systems are an important component of the Internet



of Things. They will also have many uses in the smart cities initiative which is currently being promoted by the Government of India. The confluence of RFID systems, Internet of Things, Global Positioning Systems, Cloud Computing, and Big Data analysis will lead to a large number of innovations. It is a rich area for start-up entrepreneurs to explore. There are also many innovative uses of RFID systems in medicine, biology experiments, and scientific instrumentation that students may discover.

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