Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 5, Issue 04, April -2018

PLANAR ANTENNA ARRAY DESIGN CONSIDERATIONS FOR RFID ELECTRONIC TOLL COLLECTION SYSTEM

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Abstract—*This paper deals with the design of radio-frequency identification (RFID) reader for electronic toll collection (ETC) systems. The ETC scheme herein considered comprises a planar antenna array as radiating element of the RFID reader. This reader is required to be capable of alternatively illuminating three (or more) road surface portions called coverage areas, where a transponder (tag) might be present. Coverage areas have to be well-defined in order to avoid collision. This paper treats with the design of the RFID reader, with special emphasis on the coverage area synthesis in the practical case of a limited size antenna array. This paper also introduces the implementation and design of an active RFID tag based system for automatically identifying running vehicles on roads and collecting their data. The architecture and the basic principles of design of the system are presented; including reading equipment (readers and antennas) and active electronic tag. Finally, the effectiveness and efficiency of the system is analyzed as a whole.*

Keywords*: Gateless Tax Collection, ETC- Electronic Toll Collection, RFID-Radio Frequency Identification, Toll booth, COM-Communication Port*

I. INTRODUCTION

Electronic toll collection (ETC) is a well known technology in the intelligent transportation system (ITS) area which enables the electronic collection of toll payments. It has been studied in the last forty decades, and applied in different contexts, e.g., highways, bridges, tunnels, etc. ETC systems are usually developed by means of radio frequency identification (RFID) technology. A RFID-based ETC system consists of two main factors such as a reader and a transponder (or tag). Passive tag systems are usually preferred due to its main advantage of being cheaper. The reader is placed at a certain height above the lane and irradiates energy toward the tag (placed on a vehicle) in order to enable a communication link.

The electronic collection process usually involves more steps: identification, classification, transaction, and, eventually, violation enforcement. Obviously, each of these steps needs to be executed in that specific order; further, it requires a certain period of time to be concluded. For this reason, a good solution might be to provide a multitude of active areas, i.e., spatial portions in which the reader can exchange data with the tag (herein called *coverage areas*), to separate the execution of these processes, and also to guarantee a sufficiently long connection time to conclude the electronic collection. Such a system is described. This manuscript describes some project choices of such a RFID-based ETC system. In our example, the ETC system comprises a RFID reader, placed at a certain height, which is able to irradiate toward three different directions, not in the same time, in order to illuminate three different areas on the road surface where a transponder (or tag) might be present. These areas have well-defined sizes in order to avoid collision, i.e., to illuminate more than one tag per time. The RFID reader is realized by means of a planar antenna array, and this paper copes with the design of this array, with particular emphasis on the practical case of a size constrained RFID reader, and the antenna weights synthesis. This paper is organized as follows. In Section II, a brief description of the RFID-based ETC system is provided. Some system requirements are defined in III. Section IV introduces the design choices of the antenna array and the antenna weights synthesis algorithm. In Section, some numerical results are reported to demonstrate the ability of the proposed method to achieve the required coverage areas.

II. SYSTEM DESCRIPTION

The ETC system is presented in Fig. 1. It is composed by a RFID reader placed at height hA, and one or more RFID tags, i.e., vehicles, that move through Ncz road surface portions called coverage areas. The coverage areas have to be properly defined in order to limit the probability of multiple tags interrogation, i.e., collision. In particular, inspired by the real dimensions of a highway access road, we have defined circular coverage areas with wR = 3.3 m width.

Moreover, since a vehicle length is usually from 2.5 m to 3.5 m, we have subdivided the 12 m road length of interests into Ncz = 3 portions, each of 4 m length. Obviously, different choices might also be proposed. For example, overlap of coverage areas might be acceptable to guarantee link continuity from the first to the last coverage areas. For this reason, we have extended the length of the coverage area such that lcz = 4.5 m. Finally, hA = 5.5 m, and a θA = 45 deg mechanical tilt is applied on the RFID reader. It should be noted that, in a real application, hA represents the relative height from the tag to the reader. The objective of this paper is to illustrate how to design the RFID reader based on downlink considerations. In particular, we herein consider the practical case of a constraint in the maximum antenna array size

III. SYSTEM REQUIREMENTS

Some systems requirements have to be defined before proceed with the antenna array design.

A. Maximum range

Let us first consider the signal attenuation through a loss transmission path, described by the well-known Friis attenuation

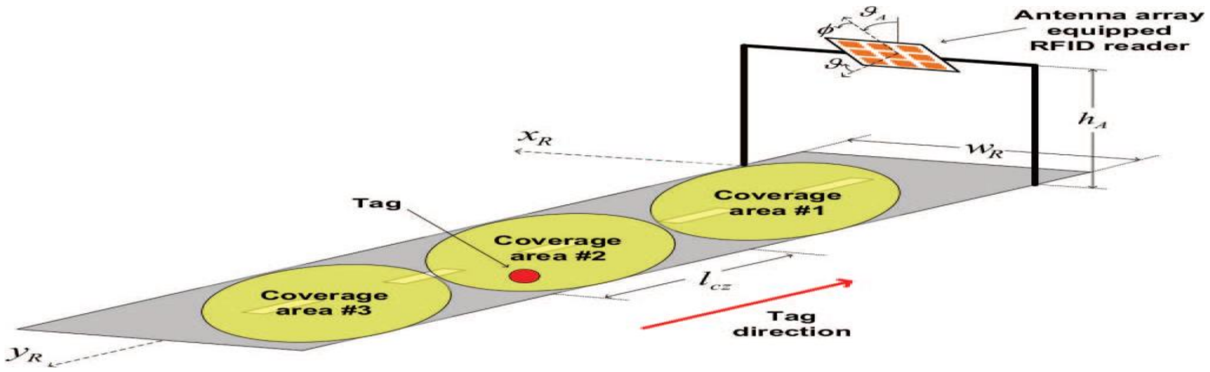

Fig 1: ETC system

Example with $N_{cz} = 3$. Formula (quantities expressed in dB)

$P_r = P_t + G_t + G_r + PL$ (1)

Where P_r and P_t are the received and transmitted power, respectively, G_t and G_r are the transmitter and the receiver antenna gain, respectively, while PL represents the path loss. RFID standards limit, in real applications, the sum of the transmitted power and the transmission gain, called *effective isotropic radiated power* (PEIRP) . Furthermore, in an ideal case of a line-of-sight (LOS) propagation channel, PL = 20log10 (λ0 4πr), where λ0 is the wavelength, and r is the distance from the transmitter to the receiver. Thus, since the received power should be larger than a threshold value Pth,

It can be rewritten as $r \leq \lambda 0\ 4\pi\ 10 - P\text{th} - P\text{EIRP} - Gr20$

It should be noted that receiver antenna gain is usually in the order of few dB, so the maximum system range is prevalently limited by both the maximum EIRP and the working frequency. Furthermore, it might be of interest to maximize the transmitter antenna gain to reduce power consumption.

B. Coverage areas

The most important part of the ETC system design is the synthesis of the coverage areas. In particular, a coverage area is defined as a road surface portion in which the received power is equal or larger than the threshold power Pth. In this way, when the RFID reader is illuminating a specific coverage area, the collision probability, i.e., the probability that more than one tag per time receives a sufficient power quantity to be linked, is minimized, and also the probability that a tag in that area is linked is maximized. For this reason, the RFID reader is required to be capable of irradiate energy in a very small portion of the road surface. From an antenna array point of view, this leads to design an array with a small beam width and minimized side lobe level. Moreover, it is required to synthesize a constant power line, i.e., the bound of the coverage area, minimizing its power level i.e. side lobe level. In this way, it is possible to maximize the received power into the coverage area. For example, if the coverage area bound is a −3 dB line, it means that the transmitted power will be adjusted in such a way that the maximum received power into that coverage area will be 3 dB more than the threshold Pth. But, if the coverage area bound is a −8 dB line, the maximum received power will be 8 dB more than the threshold power, yielding an improvement of the overall system performance.

C. Working frequency

Frequency band assessment regulations fix the possible working frequency and the maximum PEIRP so, the choice is limited to the proposed values. In particular, the frequency mainly affects two design parameters: maximum range and antenna array beam width. A trade-off has to be constituted in order to comply with the project requirements.

D. Antenna array beam width

Section III-B remembers the importance of having a RFID reader with small beam width capability, which means, in the practical case of a size constrained antenna array, having high frequency. In fact, for a broadside steered linear equal spaced array of N elements with interelement distance d, it is possible to approximate the half-power beam width (HPBW) as

HPBW ≈ 0.886 $b_f \lambda_0 / L$ [rad]

where $L = Nd$ is the approximated dimension, while b_f is the so called *broadening factor* which takes into account the effect of a specific synthesis scheme, i.e., the choice of the antenna amplitude excitations.

IV. PROPOSED SYSTEM

This project deals with the simplification of procedure followed by passengers to pay toll at toll collection booths, like making it automated, vehicle theft detection etc. All these activities are carried out using single smart card (RFID tag), thus saving the efforts of carrying money and records manually.

A. Automatic Toll Collection:

The RFID Readers mounted at toll booth will read the prepaid RFID tags fixed on vehicles' windshield and automatically respective amount will be deducted. If the tag is removed from the windshield then cameras fixed at two sites at toll plaza take snaps of the front and back number plate. Since every vehicle registration ID is linked to users account, toll can be deducted from the account bank directly.

B. Vehicle Theft Detection:

When vehicle is stolen the owner registers complaint on the website with its registration ID and unique RFID tag number. Now when stolen vehicle passes by the toll plaza, the tag fixed on it is matched with the stolen vehicle's tag in the database at the toll booth.

C. Signal Breaking Avoidance:

The vehicle ignoring the traffic signal will be detected by the RFID readers fixed at signal crossing and will be notified to the traffic police. This can be done efficiently and great accuracy.

D. Tracking over speeding Vehicle:

Vehicle travelling above speed limit can be tracked with 100 % accuracy.

V. METHODOLOGY

Whenever any person buys a vehicle, one first needs to get his or her vehicle registered at the RTO office. RTO officials will not only assign a number plate to it but also will give a RFID enabled smart card or a tag. This card will have a unique ID feasible to use with that vehicle only. They will also create an account for the use of that particular smart card and maintain transaction history in database. User needs to deposit some minimum amount to this account. Every time a registered vehicle approaches the toll booth, first the Infrared sensors will detect the presence of the vehicle. It will in turn activate the RFID circuit to read the RFID enable smart card fixed on the windscreen of the vehicle. Transaction will begin, depending upon the balance available toll will be deducted directly or the vehicle will be directed towards another lane to pay tax manually. The software further updates the details in the Centralized database server. It also triggers mechanism to generate the bill and will be sent to user as a text message.

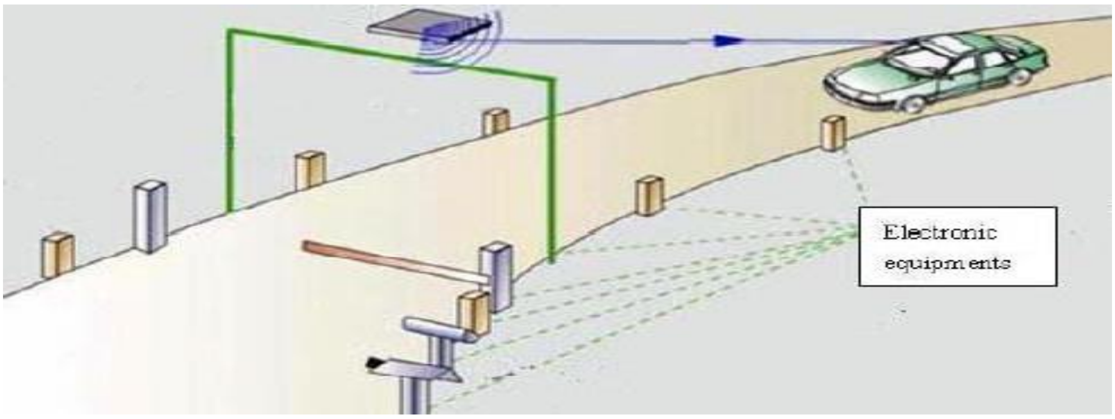

Fig 2: Working module

On the other hand, whenever any vehicle owner registers a complaint to RTO office regarding theft respective entry is made in the database. Now any vehicle arriving at toll booth with same ID as already present in stolen vehicle category will be easily identified as the ID assigned with it is unique. All the toll plazas will be connected to each other along with the centralized server in the form of LAN. Updates of any sort of transaction will be immediately updated to local database and centralized server.

VI. IMPLEMENTATION

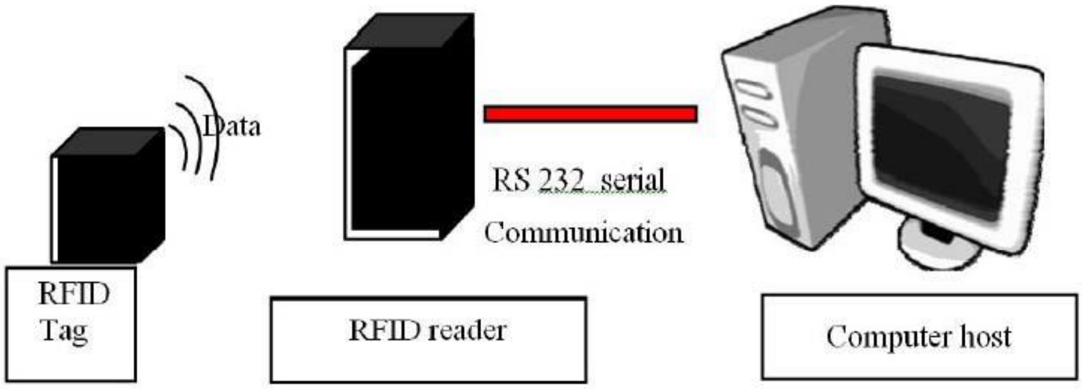

Fig 3: Hardware assembly

EM-18 RFID CHIP

Fig 4: EM-18 RFID reader module

Features

Features of RFID chip EM-18

- **RF transmit frequency** 125KHz
- **Supported standards** EM4001 64-bit RFID tag compatible
- **Communications**
- **Interface** TTL Serial Interface,Weigand output
- **Communications**
- **Protocol** Specific ASCII
- **Communications**
- **Parameter** 9600 bps,8,N,1
- **Power Supply** 4.6V-5.5V DC +/- 10% regulated
- **Consumption Current** 50mA<10mA at power down mode
- **Reading Distance** Up to 100mm,depending on tag
- **Antenna** Integrated
- **Size(L*W*H)** 32*32*8mm

RFID based toll collection system is used as a technology for fast and efficient collection of toll at the toll plazas. This is possible as the vehicles passing through the toll plaza do not stop to pay toll and the payment automatically takes place from the account of the driver. The electronic toll lanes are set up with the special antennas that continuously send out signals. These signals are used to automatically identify the vehicles that travel by them. To use the electronic toll facility, the driver needs to set up an account and get an electronic transponder fixed in the vehicle. These transponders commonly known as the tags are usually fitted on the windshields of the vehicles. The tag has all the information regarding the patron's account. The antenna continuously sends out a radiofrequency (microwave) pulse, which returns only when it hits a transponder. These pulses are returned back from the transponder and are received by the antenna.

These microwaves reflected from the tags contain information about the transponder's number, patron's account, balance, etc. Other information such as date, time, and vehicle count could be recorded depending upon the requirement of the data needed by the toll agencies. After encrypting the contents of this microwave, the unit then uses fiber-optic cables, cellular modems or wireless transmitters to 15 send it off to a central location, where computers use the unique identification number to identify the account from which the cost of the toll should be deducted. This system uses diverse technologies for its working.

Figure 4 shows the working of the electronic toll collection system with its components. These components may vary depending upon the technology used. As the vehicle enters the toll lane, sensors (1) detect the vehicle. The two antenna configuration (2) reads a transponder (3) mounted on the vehicle's windshield. As the vehicle passes through the exit light curtain (4), it is electronically classified by the treadle (5) based on the number of axles, and the ETC account is charged the proper amount. Feedback is provided to the driver on an electronic sign (6). If the vehicle does not have a transponder, the system classifies it as a violator and cameras (7) take photos of the vehicle and its license plate for processing.

Working arena

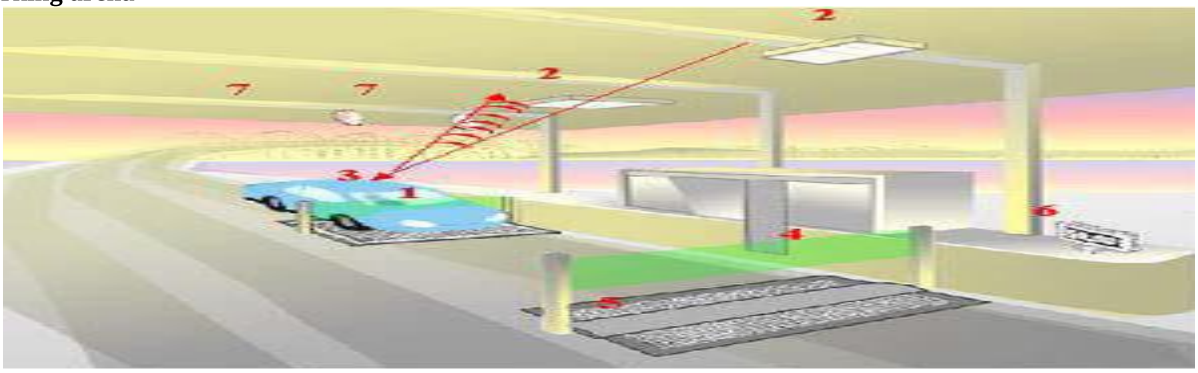

Fig 5: Implementation of RFID based toll collection system

Architecture of RFID based toll collection system

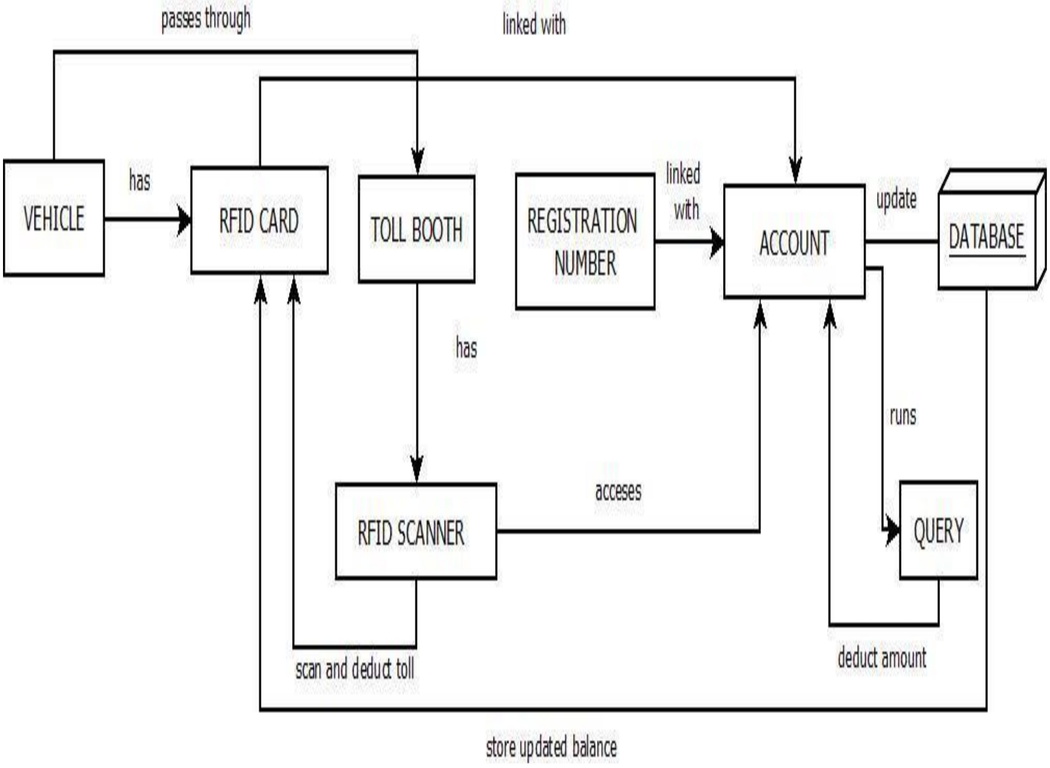

Fig 6: RFID based toll collection system

The main system components are as follows:
1) RFID tagged vehicle
2) Toll booth equipped with RFID scanners
3) Vehicle registration plate

4) Centralized database
5) Cameras
6) Laser transponders.

These components of the RFID based toll collection system technology work as follows:

A. Automatic Vehicle Identification -- The automatic vehicle identification (AVI) component of this system refers to the technologies that determine the identification or ownership of the vehicle so that the toll will be charged to the corresponding customer.

B. Automatic Vehicle Classification -- Vehicle type and class may have differentiated toll amount. The vehicle type may include light vehicles like the passenger car or heavy vehicles like recreational vehicles. A vehicle's class can be determined by the physical attributes of the vehicle, the number of occupants in the vehicle, the number of axles in the vehicles and the purpose for which the vehicle is being used at the time of classification (or some combination of these determinants). Some toll agencies use as many as 15 or more vehicle classes to assess tolls, although for toll collection applications, four or five classes are more typical.

C. Video Enforcement Systems -- When used for electronic toll collection, the video enforcement system (VES) captures images of the license plates of vehicles that pass through an ETC tollbooth without a valid ETC tag. Although the deployment of these technologies makes the initial cost of installation very high, but there exits huge benefits accompanied with such high investment. These benefits are discussed in the upcoming section.

The flow chart for the proposed system is shown as Follows:

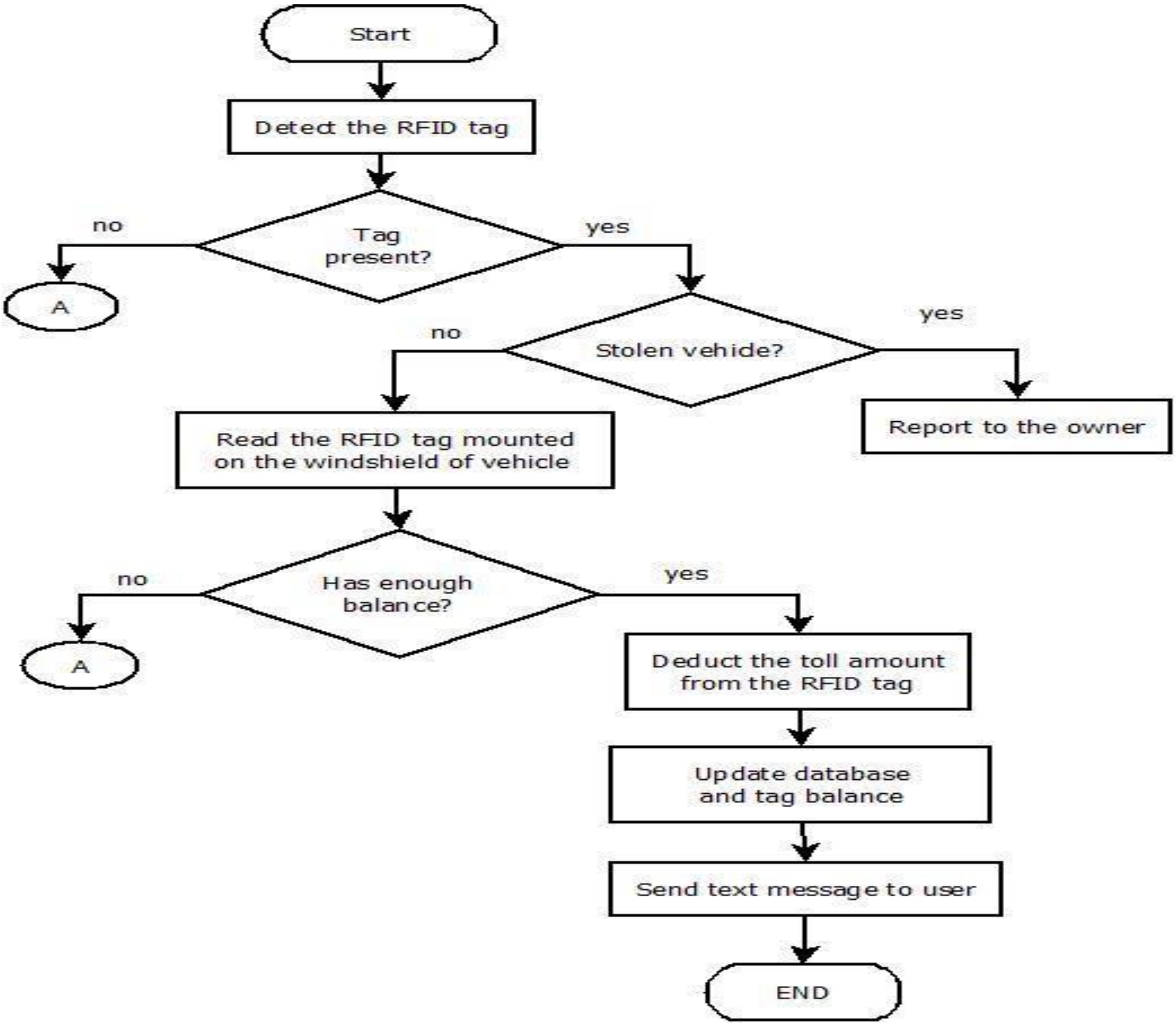

Figure 7.2: Working of system

Flowchart 2: Working of the RFID based toll collection system and theft detection system (continued...)

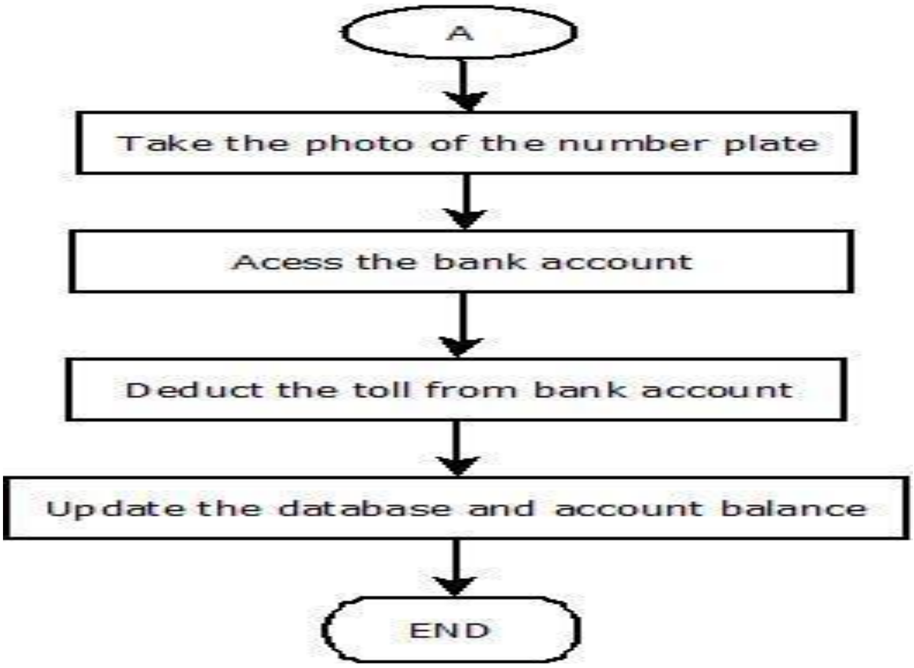

Fig 7: Working of system

VII. APPLICATION TECHNIQUES AND PRINCIPLES

Typical ETC systems are comprised of four subsystems: automatic vehicle classification (AVC), violation enforcement system (VES), automatic vehicle identification (AVI), and transaction processing, which include a back office and customer service center.

A. Automatic Vehicle Classification:
AVC systems consist of sensors installed in the toll lanes to detect and classify the vehicles for proper tolling. The AVC technique is most commonly performed using overhead equipment (laser or infrared detectors) or intelligent detector loops embedded in the pavement, but the detectors can also be placed on the roadside. The sensors are capable of perceiving and classifying vehicles in the open road tolling or all electronic tolling environments.

B. Violation Enforcement System:
The primary goal of VES is to reduce the number of toll evaders with the assistance of multiple types of solutions. These methods range from fairly basic (audible and/or visual alarms) to complex systems, such as automatic license plate recognition camera-based solutions. Police enforcement and toll gates are other types of successful VES but can be costly and inefficient for high traffic volumes.

Camera-based VES captures images of each vehicle’s front and/or rear license plates, depending on the toll authority’s regulations. The necessary equipment consists of a camera (or array of cameras), an illumination system, and a controller card or computer that interfaces with the lane controller and/or the back office. A camera-based VES with plate recognition serves a dual purpose of enforcement and video tolling.

C. Automatic Vehicle Identification:
The AVI systems properly identify each vehicle to charge the toll to a particular customer. This ETC method is typically done with various AVI technologies such as a bar coded label affixed to the vehicle, proximity card, radio or infrared transponder, and automatic license plate recognition. A majority of the AVI systems used involve radio frequency identity (RFID) and plate recognition technologies. The RFID system uses an antenna to communicate with a transponder in each registered vehicle, while video tolling identifies the license plate and charges a customer or sends a bill to un-registered drivers with help from the Department of Motor Vehicle’s address database.

D. Back Office and Customer Service:
The back office consists of the host and/or plaza system, customer service center, and violation processing center. The main functions of the host and plaza systems are to aggregate transactional data from all the lanes, data summarization, report generation, download of files such as a toll rates, toll schedules, and transponder status list. The customer service center is responsible for processing the AVI and video tolling transactions, matching transactions with account holders, debiting the correct toll amount, managing accounts, generating a valid tag list, and providing customer support to name

a few. The violation processing center's main function is to process the images of the licenses plates, identify violators, and mail notices.

E. APPLICATIONS

- RFID technology can dramatically decrease vehicle queuing at Automobile toll plazas, speed throughput, and significantly improve the quality of life for commuters and communities.
- Electronic toll collection transactions to occur under normal highway driving conditions.
- Open road tolling eliminates plaza barriers and creates a new toll road design that mitigates congestion.
- Open road tolling gives toll authorities the flexibility to set variable pricing for toll services.
- Variable pricing models can be pre-established, or modified in real time, responding to existing traffic situations.

VIII. RESULT

Most of the technological issues have been overcome after two decades of successful ETC implementations. The current issues with implementing ETC systems are related to interoperability and technology selection. Although all the toll facilities within Texas are currently interoperable (that is, one tag can be used on all toll facilities), there is a lack of interoperability with other states and with toll facilities at border crossings and in Mexico. The need for interoperability between border crossings and toll roads within the United States will continue to increase as toll roads are built near the border. Technology selection directly impacts interoperability. If a toll agency selects a different RFID protocol then it might not be able to read customers from away agencies. Cities and local toll authorities should work together to create a compatible system throughout the state.

IX. CONCLUSION

The electronic toll collection system in expressway based on RFID, a design scheme was put forward. It has characteristics of low cost, high security, far communication distance and high efficiency, etc. It is not only can improve technology level of charge, but also improve passage ability of expressway. Electronic toll collection system is an effective measure to reduce management costs and fees, at the same time, greatly reduce noise and pollutant emission of toll station. In the design of the proposed Electronic toll collection (ETC) system, real time toll collection and anti-theft solution system have been designed. This reduces the manual labor and delays that often occur on roads. This system of collecting tolls is eco-friendly and also results in increased toll lane capacity. Also an anti-theft solution system module which prevents passing of any defaulter vehicle is implemented, thus assuring security on the roadways.

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