Efficient Design And Implementation of Semi-Passive RFID Tag With Three Axis Base Station Antenna Displays in Three-Dimensional Virtual Indoor Map

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Abstract- *We develop and implemented the prototype of low-cost semi-passive radio-frequency identification (RFID) system with capability of localization and tracking of semi-passive tags. Recently, RFID system has become popular and has been growing rapidly as identification and tracking technology. An ultra-high frequency signal allows the wake-up of the tags enabling the reduction of energy consumption and ensuring compatibility with existing RFID systems. The overall system as well as the reader and tag architectures are introduced. localization system is used to identify the position of a semi-passive. These RFID tags rely on a simple load modulation to backscatter ID and data back to the reader over several meters distance. Here we have Microstrip Narrow Beam antenna which act as the reader for the semi-passive RFID tag, operates at the frequency of 2.4GHz. And a semi-passive build with the base of Arduino nano board and RF transmitter/receiver. The transponder receives the output from the RFID tag are transmitted to Mobile App through wi-fi module. Moreover, the collected experimental results allowed to outline an experimental demonstrating how accurate RFID tag prototype can achieve its destination.*

Keywords- Microstrip Narrow Beam Antenna, Semi-Passive RFID Tag, Arduino Mega, Arduino Nano, NRF 24L01 RF Transmitter/ Receiver and Wi-fi Module

I. INTRODUCTION

Real-time localization and tracking of objects or humans have received considerable research attention in many applications such as emergency search and rescue and patient tracking applications. Accuracy, reliability, and estimation speed, are the key issues for an indoor localization and tracking system. Conventional techniques for indoor localization are based on various types of infrastructure support, which include technologies developed based on ultrasound, imaging, infrared, ZigBee, Bluetooth, laser, ultrawideband (UWB), and radio frequency identification (RFID) [1]. Among the aforementioned methods, RFID technology provides an accurate tool for indoor localization with advantages of high resolution of position estimation, flexibility, and low-cost of system installation. RFID system has two main components, transponders (RFID tags) and detectors (RFID readers). In addition, RFID tags can be passive, active or semi-passive, depending on having a power supply and capability of initiating a communication with the reader [3].

The importance of wireless communication and multimedia services is increasing the efforts of design and implementation of novel microstrip patch structures from miniaturized electronic circuits to the antenna arrays. Microstrip patch antennas have found extensive application in wireless communication system due to their advantages such as low profile, conformability, low-cost fabrication and ease of integration with feed network [1]. Microstrip antenna in its simplest form consists of a radiating patch (of different shapes) which is made up of a conducting material like Copper or Gold on one side of dielectric substrate and a ground plane on the other side [3], It is used in communication systems due to simplicity in structure, conformability, low manufacturing cost, and very versatile in terms of resonant frequency, polarization, pattern and impedance at the particular patch shape and model, it can be used for high frequency and high speed for data transfer.

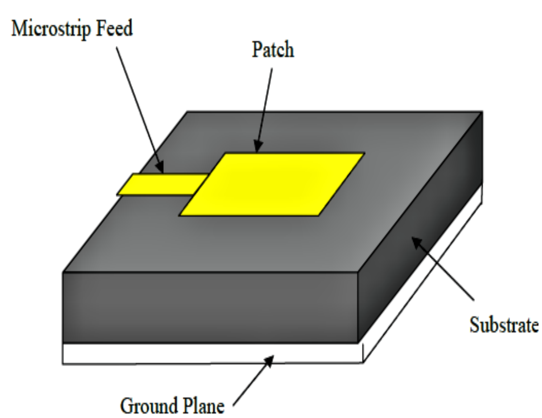

Figure 1. Microstrip patch antenna geometry

In various communications and radar systems, microstrip array antennas are greatly desired. They are used, to synthesize a required pattern that cannot be achieved with a single element. In addition, they are used to scan the beam of an antenna system, increase the directivity, and perform various other functions which would be difficult with any one single element. The elements can be fed by a single line or by multiple lines in a feed network arrangement. In this prototype we are using the series-feed.

Compared to a traditional Auto-ID system, the RFID technology has many advantages. Firstly, the identification of tags is more accurate and the distance is more flexible. Secondly, the maximum memory capacity of RFID tags can be several megabytes which is much more than that of the traditional Auto-ID's. Thirdly, RFID has better performance in anti-pollution, because the data is saved in a chip wrapped by the tag. Finally, RFID tag is rewritable. We can add, modify and delete the data stored in the tag repeatedly. In the following sections we can see the design and implementation of Microstrip Narrow Beam and Semi-Passive RFID tag, how they operate at 2.4GHz frequency [2], how the tag responds to the transponder and locating the precise location of the product with the help of Mobile Application.

II. MICROSTRIP SINGLE ELEMENT PATCH ANTENNA DESIGN

For a rectangular patch, length L is usually $0.3333\lambda 0 < L < \lambda 0$, where $\lambda 0$ is the free-space wavelength. Patch is usually very thin such that patch thickness t is very less than $\lambda 0$. The dielectric constant of the substrate $\varepsilon_r$ranges from 2.2 to 12. The thickness h of the dielectric substrate is usually in the range $0.003\lambda 0 \leq h \leq 0.05\ \lambda 0$ [2].

The Performance of the microstrip antenna depends on its dimension. Depending on the dimension the operating frequency, radiation efficiency, directivity, return loss and other related parameters are also influenced. For an efficient radiation, the practical width of the patch can be written as:

$$w = \frac{c}{2fr\sqrt{\frac{2}{\varepsilon_r + 1}}}$$

The length of the antenna becomes

$$L = Leff - 2\Delta L$$

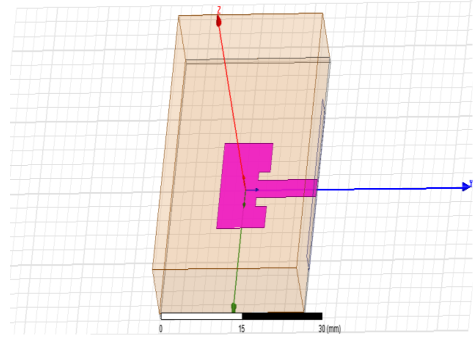

Figure 2. Single element rectangular patch antenna

III. MICROSTRIP PATCH ARRAY ANTENNA DESIGN

Microstrip antennas are used not only as single element but also very popular in arrays. Main limitation of microstrip is that it radiates efficiently only over a narrow band of frequencies and they can't operate at the high-power levels of waveguide, coaxial line, or even stripline. This can be minimized with the help of various array configurations, feeding methods, dielectric materials and ground planes[2]. Antenna arrays are used to scan the beam of an antenna system, to increase the directivity, gain and enhance various other functions which would be difficult with single element antenna [5].

A. Software Tools

The software used to model and simulate the microstrip patch array antennas is HFSS. HFSS is a high-performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. An soft HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems [2].

B. Feed Network

In the microstrip array, elements can be fed by a single line or multiple lines in a feed network arrangement. Feeding methods are classified as:

- Series feed network
- Corporate feed network
- Corporate-series feed network.

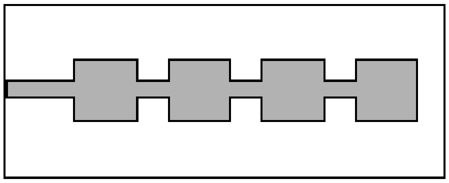

Figure 3. Series feed

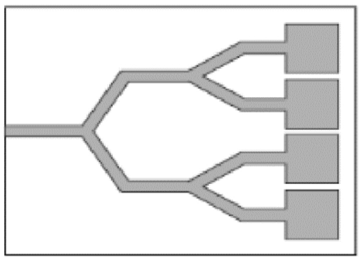

Figure 4. Corporate feed

The series feed (Fig. 3) usually consists of a continuous transmission line from which small proportion of energy are progressively coupled into the individual element disposed along the line. The series feed constitutes a traveling wave array if the feed line is terminated in a matched load. Here the difference between the series feed and corporate feed. A corporate feed (Fig. 4) is most widely used parallel feed configuration. For a uniform aperture distribution, the power is equally split at each junction. However different power divider ratios can be chosen to generate a tapered distribution across the array. The disadvantages of this type of feed is that it requires long transmission lines between radiating elements and the input port hence the insertion loss of the feed network can be prohibitively large thereby reducing the overall efficiency of the array[2]. The series-corporate feed is the combination of series feed and corporate feed; it is frequently used for array antennas to get benefits of both feeding networks. In this paper the series, corporate and series corporate-feed with inset feed is being discussed for the antenna array design. When feeding is bed, the total efficiency could be reduced to a low level which makes the whole system to be rejected.

The effects of the feed network are important in high gain microstrip antenna array with large number of radiating elements and complicated feed network.

C. *Design of Microstrip 16×1 Patch Array Antenna*

Using the same dimensions mentioned above and a spacing of $\lambda/2$ between the patch elements, an array of 16 rectangular patches is designed[4]. The patch elements are connected using a quarter wavelength microstrip lines in series feed and T- junction power dividers are used in corporate feed and both for series-corporate feed. The structure of the power divider is symmetric. The FR4 epoxy glass substrates are the material of choice for most PCB applications. The material is very low cost and has excellent mechanical properties, making it ideal for a wide range of electronic component applications. the use of FR4 is unlikely to be viable for antenna feeding structures due to its high losses [8].However, for high density microwave circuits where path lengths are short and for broadband antenna elements, where losses and absolute dielectric constant values are less critical, the material could be used in place of more conventional microwave substrate materials, offering significant cost savings.

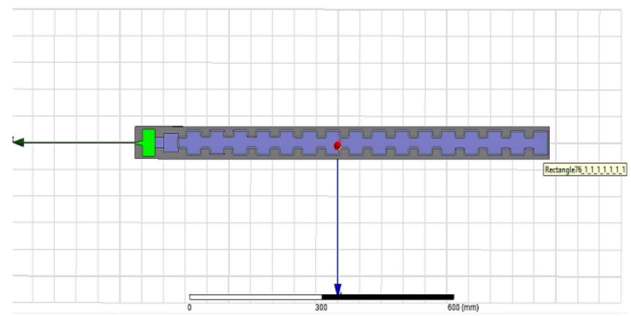

Figure 5. Rectangular 16×1 patch array antenna with series feed

Here the thickness of the board will be 3.2mm and the copper thickness is 1 oz (~35µm thick or 1.4 mils) — Standard internal layer copper thickness for standard construction product for 1 oz and 2 oz finished copper weight selections. This is also the standard starting copper weight on the external layers for PCBs with the 2 oz finished copper weight selection [8]. Here the copper area size is ($950 \times 60\ mm/pcs$).

D. *System Description for transponder*

Let consider the square room which has the sides of A, B, C, and D. where the antenna A_1 and A_2 placed in the X-axis (A-side) exact opposite to the C-side and Z- axis(B-side) exact opposite to the D-side. Let X_B and X_E denotes the beginning and ending of the antenna A_1, Here the antenna scans horizontally from 0 to 180 degree, beam width of 6 degree with the help of stepper motorto get an angle of the object present in X-direction when the transponder receives the correspondent ID from the particular angle, where that angles are stored in the controller (Arduino Mega 2560 R3). Z_B and Z_E denotes the beginning and ending of the antenna A_2 here the antenna scans horizontally from 0 to 180 degree, beam width of 6 degree with the help of stepper motor to get an angle of the object present in Z-direction, As mentioned before when the antenna receives the ID at the particular angle, where that angle will be stored in the microcontroller. Y_B and Y_E denotes the beginning and ending of both antenna

A_1 and antenna A_2(this is common for both the antenna A1 and A2) these tends to scans in vertical direction in-order to get the height of the object in Y-direction where the received ID angle will stored in the controller. Here in this prototype we had taken the 10×10 feet area (but this value may vary according to the customer room size) and we created a cube for every 15cm in that complete 10feet. In-order to create the small cube to increase the accuracy of finding the object location. Where these angles are collected in the single element and given to the wi-fi module. The below figure shows how antenna covering the entire room in all three direction.

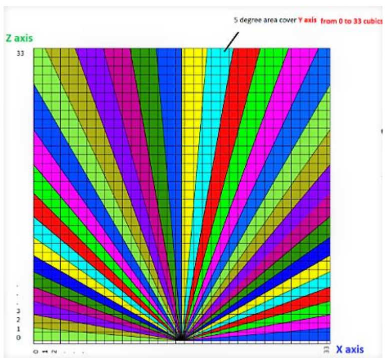

Figure 6. Antenna coverage in X-direction

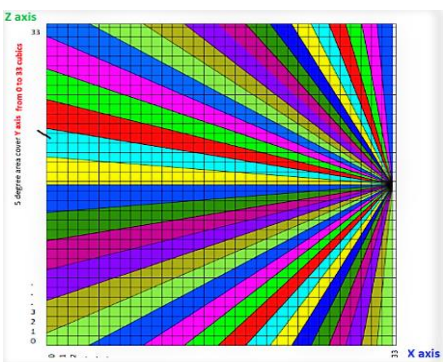

Figure 7. Antenna coverage in Z-direction

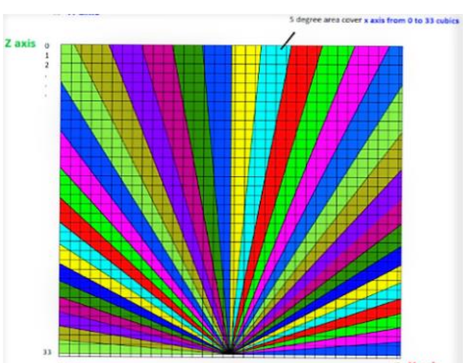

Figure 8. Antenna coverage in Y-direction

From the figure 6 and 7 shows that both the antenna starting (X_B and Z_B) are from the single point. Here the different shades show the antenna radiates in different angles [5]. While in stepper motor we programmed it to move for every 5 degree and make it to complete 180 degree. In each degree we make a minute microsecond delay for transmitting and receiving of ID. While in real-time we can't see any major delay in stepper motor.

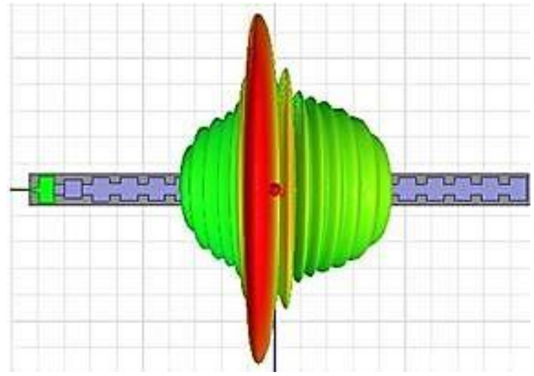

Figure 93Dplot of Microstrip patch antenna (view -I)

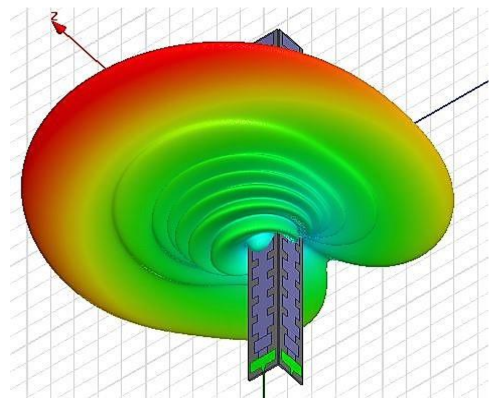

Figure 103D plot of Microstrip patch antenna (view -II)

The above two figures (9 & 10) shows the 3D plot of Microstrip patch antenna, from the above figure we can the red colour indicates the maximum power obtained from the Microstrip patch antenna.

E. Return Loss

In this part S parameter calculation has been performed for microstrip 16×1 patch array antenna with series feed network. Fig. 11 shows that the return loss for patch array antenna with series feed are -37dB at frequency 2.48GHZ[2].

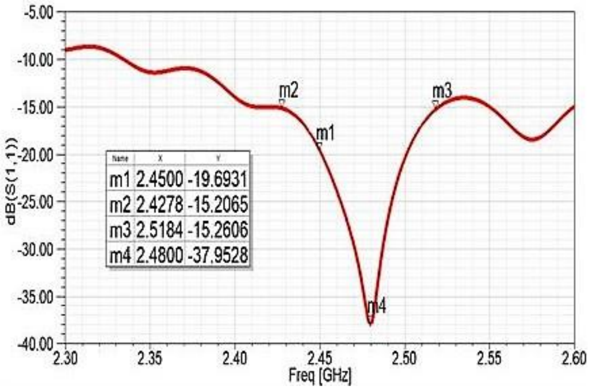

Figure 10 Return loss of the 16-elements series feed array antenna

F. *Radiation Pattern of Designed Antenna*

The representation of radiation pattern of 16×1 patch array antenna [7]excited by series feeding is shown in Fig. 11. It can be observed clearly that array antenna with series feed represents an improvement in radiation pattern.

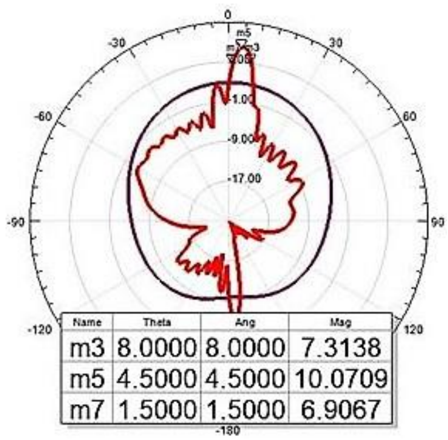

Figure 11 Radiation pattern of the 16-elements antenna array: series feed

G. *Antenna parameters*

Simulation results obtained for single patch antenna and 16 elements array antenna are presented in this Table I:

Table.1Microstrip patch 16×1 patch array antenna series feed network

S.NO.	PARAMETERS	PATCH ANTENNA
1	Resonance frequency	2.48GHz
2	Return loss	-37dB
3	Gain	10.1dB
4	Directivity	10.41dB
5	Beam width	90°

We can see from table above much improved result is achieved with 16×1 patch array antenna series feed network. Regarding to return loss we got a good result at the resonance frequency of 2.48 GHz.

IV. DESIGN OF SEMI-PASSIVE RFID TAG

For wireless communication the 2.4GHz nRF24L01, that operates within the ISM band. The transceiver IC integrates a RF synthesizer, and baseband logic including the Enhanced Shock Burst hardware protocol accelerator supporting a high speed SPI interface for the application controller. The chip has the SPI clock speed of up to 10Mhz. The 2.4GHz wireless nRF24L01 module used has a powerful transmission/reception capability, making use of the power amplifier (PA) and the low noise amplifier (LNA) full two-way enhanced power capability. The PA control is used to set the output power from the RF Transceiver power amplifier (PA). The power ranges from 0dBm to -18dBm in the transmission mode. The radio is capable of three air data rate mode 2Mbps, 1Mbps, and 250Kbps.With 2dB Antenna and data rate of 250kbps, the transmission distance can be up to 1kmmeters(3000feet) in open area, about 750 meters with 1Mbps data rate and about 520 meters with2Mbps data rate. Actually, the transmission range is very much dependent on the situation. Here the main part comes in, the nRF24L01 combines with the Arduino nano R3 board which is powered by the 9V battery. Here the semi-passive RFID tag antenna transfer its ID when it matches with code send from the Reader antenna. Semi-passive tag antenna transmits in the omni directional field which would be captured by the reader antenna again and the angle of arrival of ID will stored in Arduino Mega 2560 R3 board this procedure is repeated for all the three axis X, Y and Z. Then these angles are pushed to the Mobile application through ESP8266 wi-fi module. The below figure shows the Arduino nano R3 board connected with the nRF24L01 module.

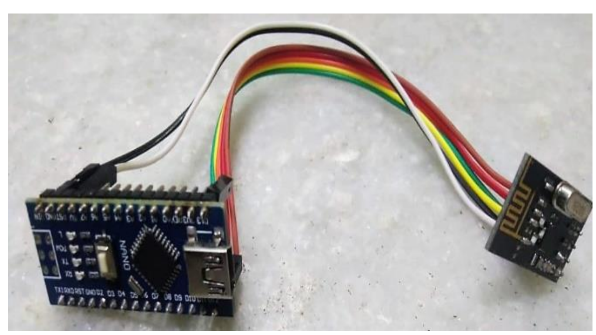

Figure 12Arduino nano R3 with nRF24L01 as semi-passive RFID tag

V. RESULTS AND DISCUSSION

When we combine the all the three angles from X, Y and Z-axis we will get the object location which we represented in cube structure. Here the final result will be displayed in Mobile application consider the square box as room which as the four side. Here X-axis and Y-axis shows the surface of the room and Y-axis shows the height of the room where it displayed next to it. The green colour cube represents the location of the object. To the right-side y-axis shows on which height the object has been located. And also, the black colour cube represents the slight antenna coverage as we said in starting of this section when we combine all the three axis there is slight possibility that antenna result can height the adjacent node around it. The below picture shows the final picture of object tracking.

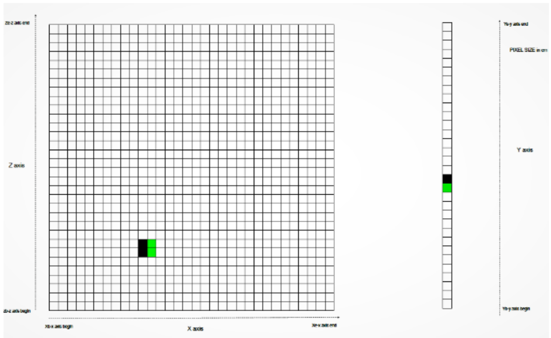

Figure 13Object location in mobile application

VI. CONCLUSION

The unique feature of this microstrip patch antenna is its simplicity to get higher performance. In many applications basically in radar and satellite communication, it is necessary to design antennas with very high directive characteristics to meet the demand of long-distance communication with high accuracy and the most common configuration to satisfy this demand is the array form of the microstrip antenna.

For an array antenna with a large number of patches, the gain and directivity increase whatever the feeding method (series, corporate or series-corporate) however observing the performance analysis of this array antenna, it is convenient to say that 16×1 patch array antenna with series feed network provides better performance -37dBreturn loss and 10.41dBdirectivity is achieved at 2.48GHz.The microstrip 16×1 patch array antenna with series feed network has the higher directive gain as well as the narrow beam width.

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