Study of a Monopulse System with RFID Antennas for Applications oriented to Retail Industry

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Abstract
Radio Frequency Identification (RFID) allows the identification and location of items using passive electronic labels. However, current RFID techniques do not locate objects precisely. The monopulse system allows to locate objects with higher accuracy using a combination of Radio Frequency (RF) beams. In this work, we present a two-antenna monopulse system implementation using RFID technologies. By combining RF beams we obtained a focused beam. We also investigated the multipath effect in this work. Our results show a monopulse system using RFID technologies with an accuracy of 84%. It can be applied in the retail industry for applications such as fitting rooms, inventory, customers’ location and others.

Author Keywords
Monopulse, RFID, Multipath, Retail, Tag, Antenna, EPC Gen 2

ACM Classification Keywords
I.5.4 [Applications]: Signal processing

Introduction
The monopulse system [1] is a Radio Frequency (RF) technique used in radar for tracking objects. An object can be detected through RF beams by the difference and the sum beams of a pair of antennas. When an object is
detected, the reflected signal is received by both beams. Then, the object can be located accurately.

By increasing the distance between antennas, both difference and sum beams also change. Figure 1 shows four figures from different antenna separations. One can see an additional, subtraction and single beam with the colors green, red and blue respectively.

Figure 1: Antennas’ separation: a) 28 cm., b) 42 cm. c) 56 cm. and d) 70 cm.

The antennas used in this project are adapted to the Ultra High Frequency (UHF) with central frequency of 867 MHz to work with Radio Frequency Identification (RFID) technology [2]. RFID is a wireless communication technology for identifying items. It is composed by an interrogator or reader and tags. As this project was initially intended for retail and supply chain scenarios, EPCGlobal [3] is the standard which defines all the features related with the communication between RFID reader and tags.

The RFID technology is applied in many scopes. It is implemented especially in the retail industry; from manufacturers to the end-user [4].

The monopulse system allows an accurate location of objects within the range of its RF beams. Moreover, with the use of RFID technologies, an object could be identified due to the unique Electronic Product Code (EPC). The monopulse system could be applied for the following scenarios in the retail industry [5]:

- **Fitting room**: A customer gets inside a fitting room to check if a garment fits on him/her. This garments has attached an RFID tag with a unique EPC. By using narrow beams from the monopulse system (see Figure 2), the RFID tag could be easily detected. Moreover, these beams will not read RFID tags from the adjacent fitting rooms avoiding mistakes. A screen inside each fitting room connected to a recommendation system could show images and description of the given garment, and suggest others to combine.

- **Inventory**: All products from a retail store which are tagged with an RFID tag can be inventoried. The monopulse system allows to read a specific area exclusively for better management of the inventory or because the difficulty of reading.

- **Customers’ location**: Since different beams are generated with the monopulse system, an RFID tag can be located within them. If customers carry a card with an RFID tag attached, they could be detected along the store and their shopping behavior studied.

- **Payment**: Cash counters could be integrated with a monopulse system for reading articles to be charged and finally sold. Due to the narrow beams, only the given articles would be read avoiding to charge others near them.
RFID hand-held reader: An RFID hand-held reader allows to read RFID tags by any employee at anytime. A given article could be easily located within a hanger/shelf due to the generated beams from the monopulse system. Employees could find a given product faster.

Experiment and Results
Experiments were carried out in the laboratory. The dimensions of this laboratory are 7x4x3.5 meters. The test of the monopulse system has been done using two Advantennas P11 [6], one AdvanSplitter [7], one AdvanReader [8] and fifty six passive tags [9] on a cardboard. The experiment was set up as shown in Figure 3. The cardboard was held on the middle of the room and in front of it, Advantennas P11 were pointing towards it. Both the center of the cardboard and the Advantennas were located in the same height from the ground.

The two Advantennas were connected using an AdvanSplitter to implement the addition beam of a monopulse system. Figure 5 shows the two Advantennas.

Since the Advantenna P11 has a size of 14 cm. of width between the center of two Advantennas will be of 14 cm.

Focus Beam
The battery of tests consisted of studying the read tags after applying Equation 1

\[ S1 - (S1 \cap S2) \]  

Where S1 are the read tags from a Single Beam (beam generate from a single Advantenna P11) or an Addition Beam (composed by two Advantennas P11 connected to the AdvanSplitter and both with the same rotation). On the other hand, S2 corresponds with the read tags from a Subtraction Beam (composed by two Advantennas P11 connected to the AdvanSplitter but one Advantenna rotated 180 degrees with respect to the other). The Equation above represents the read tags from S1 but not from S2. Figure 6 shows the results after comparing the read tags from S1 and S2. The tags along the cardboard follow a matrix of 7 rows with 8 columns. Antennas’ separation is 70 cm (center-to-center). Radiation diagram d) from Figure 1 represents the RF beams with 70 cm of antennas’ separation. The goal of this project was looking for a focused beam at the center of the cardboard. One can appreciate vertically in Figure 6 how it was achieved on the middle of the x-axis. The center of the cardboard (or region of interest) is the area delimited within the blue rectangle (see Figure 4). Accuracy is defined as the read tags exclusively from S1 within the region of interest (True Positive) plus those read tags from S1 outside this region (True Negative), divided by the total amount of tags of the cardboard. However, one should appreciate on the achieved region how there are some non-read tags. A second study was carried out in order to explain these non-read tags.

Multipath effect
Different causes were taken into account, but the that better to explains this phenomenon is the well-known multipath effect. Multipath is caused by the reflections of the generated signals through the wall, windows, floor and other surfaces. If the phase of the reflected wave is 180 degrees shifted, it creates a destructive interference and it will not read the RFID tag [10].

By using the following Equations, it is possible to find out the height where the reflected wave will impact against the cardboard.

\[ R1 = \sqrt{d^2 + (h2 - h1)^2} \]  
\[ R2 = \sqrt{d^2 + (h2 + h1)^2} \]
\[ \Delta R = R_2 - R_1 \quad (4) \]

Equations 2 and 3 are used to calculate the distance traveled by the direct and reflected waves when the height from the receiver is not same as the one from the emitter. These Equations depend on \( h_2 \). The parameter \( h_2 \) represents the different heights of the receiver (the tags).

The parameter \( h_1 \) represents the height of the emitter which in this case is fixed and \( d \) is the horizontal distance between emitter and receiver. These results are applied in Equation 4 to get the height where the reflected wave impacts on the cardboard. Finally, it is the turn to cross the result from Equation 4 (red line) and \( n^*\lambda \) values. Figure 7 adds Figure 6 and the graph calculated with Equation 4. The y-axis represents the height of the cardboard respect the floor and the x-axis different values of \( \lambda \). Horizontal magenta lines correspond with the intersection with the result from the Equation 4 and a value \( n^*\lambda \) and they match with parts of the cardboard where are some non-read tags.

Figure 7: Monopulse system - Multipath. Antenna’s separation: 70 cm., distance Antennas-RFID tags: 2.5 m. and Height: 1.1 m.

**Discussion and Future Work**

In this work, we have implemented a monopulse system suitable for RFID technologies. Results showed good performance of this system by getting a focused beam on the center of the cardboard (see blue rectangle in Figure 4). Also, we considered the multipath effect in our work. Furthermore, we observed as some tags were not read due to that. We got an accuracy of 84% with the implementation of the monopulse system. Equation 5 calculates the accuracy of the monopulse system.

\[ \frac{(True\ Positive + True\ Negative)}{All\ tags} \quad (5) \]

Some future tasks will be to realize tests in zenithal position to obtain results without the influence of the multipath effect. Moreover, an antenna type microstrip could be built with the monopulse system and some tests performed in a real store.

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