A Moving Object Tracking Application FOR USING Smart Antenna Systems

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Abstract: - In mobile communication systems, the ever-increasing number of users necessitates the need for location and position information, as well as the need to provide sufficient capacity. In the studies conducted, to respond to location and position information, the solutions presented result in the presence of a continuous internet, satellite environment, or wireless system. In this study, it is aimed to determine location and position information without internet, satellite, and wireless systems. For this purpose, an original smart antenna design operating in the 0.8-1.6 GHz frequency range in the ISM band has been made. Smart antennas designed for this purpose increase signal quality, suppress noise, provide power savings, and increase system capacity by providing the opportunity to benefit effectively from the wireless spectrum.

Key-Words: - Smart Antenna, Adaptive Arrays, Mobile Communication, Beam Forming, Orientation, Moving Object Tracking.

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1 Introduction

The increasing demand for wireless communication technologies and networks has led to the emergence of high bandwidth needs. One of the most important methods suggested to meet the increasing bandwidth and capacity needs is the development of antenna systems. Initially, antennas were the least important part of wireless communication systems, and communication was carried out using omnidirectional/isotropic antennas, [1]. Increasing bandwidth and capacity needs have led to the emergence of smart antennas.

Smart antennas are systems that increase the performance of wireless communication systems and allow the most efficient use of the bandwidth needed to provide high efficiency in heavy traffic and user environments, [2]. Initially, smart antenna systems were designed to be used in military applications to suppress interference and jamming signals sent by the enemy, [3].

Later, with the emergence of powerful, low-cost, and complex digital signal processors that can perform complex operations in a very short time and the development of software-based techniques, smart antennas have become more widely used in cellular communication systems.

2 Smart Antenna Systems

Smart antennas are an antenna technology developed for wireless systems formed by the combination of a certain number of antenna elements in an array. The signal received from the antenna elements is shaped to form a dynamic beam pattern. By using digital signal processing systems and appropriate software, the beam pattern is directed in the desired user direction. Thus, since signal transmission is provided only in a certain direction, the power density is focused at a single point, allowing the interference effect to be minimized for other users. In addition, unwanted noise in the environment is reduced, [4].

In smart antenna systems, the antenna itself is not smart. The antenna is only a mechanical element used to radiate the electromagnetic signal into space or receive it from space. What makes the antenna smart is the antenna elements that come together in an array and the signal processing algorithms used. A smart antenna system consists of a certain number of beam-emitting elements, a network, and control units. The control unit is the brain of the smart antenna system and performs this task using a digital signal processor (DSP). The processor unit, which is usually located in the base station; In order to provide efficient communication, constantly controls the parameters coming to the antenna and ensures that the beam pattern is focused in the direction of the desired user, [5].

3 Smart Antenna Structure

In general, the adaptive antenna architecture consists of five simple subsystems. These are: antenna, radio frequency (RF) start, down converter section, data acquisition system, and signal processing module (DSP). It is possible to extend this architecture by including adaptive equalizers.

3.1 Simple Smart Antenna Architecture

In general, a smart antenna should fulfill the following three tasks.

First, it is to obtain the necessary information or signals from the antenna array, then to convert this information into a suitable format for processing. For technologies that use digital systems, this means converting analog signals into digital signals using analog-digital converters (ADCs).In addition, another task is to collect the information coming from the antenna elements individually in a suitable format, amplify it to reach the desired signal, and change the coefficients to minimize the interference, [6].

In principle, smart algorithms can be applied to microwave-based methods or DSP-based techniques. In addition, smart antennas can be designed for both wideband and narrowband applications. However, in the discussions about smart antennas, it is assumed that narrowband signals are used, so the time delay can only be shown as a phase shift in the carrier. Therefore, the process of directing zeros to the interference and turning the antenna characteristic in the desired direction can be achieved by changing the phase and amplitude of the signals of the elements in the array. The narrowband approach greatly simplifies the system architecture, [7].

3.2 Traditional Microwave-Based Architecture

Traditionally, the majority of smart antenna structures employed in military radar applications have relied on microwave-based architectures. In these systems, electronically controlled microwave phase shifters and attenuators are utilized to generate the desired radiation pattern and adaptive beamforming characteristics. However, several limitations arise from the use of such components. Because phase shifters and attenuators typically incorporate multiple switching diodes to achieve various discrete phase and amplitude levels, inconsistencies may occur between different switching states. Furthermore, since both phase and amplitude adjustments are performed in relatively coarse and widely spaced steps, the resulting quantization can introduce subtle but significant errors into the antenna's performance. These hidden inaccuracies may degrade beamforming precision, reduce target detection capabilities, and ultimately affect the overall reliability of smart antenna systems operating in demanding military environments, [8].

These are listed below.

- The system can be easily affected by a large number of errors, including quantization errors in phase shifters and attenuators.
- Due to the determination of phase and amplitude with wide step intervals, it is possible that the antenna array cannot direct the antenna characteristics and zeros exactly to the desired direction. Therefore, it is possible that the gain decreases and the interference cannot be suppressed at the desired level.
- Unequal losses may occur as a result of switching different structured diodes in the transmission line for different interference structures. System performance cannot be at the desired level due to different interference.
- System structure is not flexible. The hardware designed once cannot be created according to different interference scenarios.
- Another problem is the high cost of multiple channels and multiple beams.

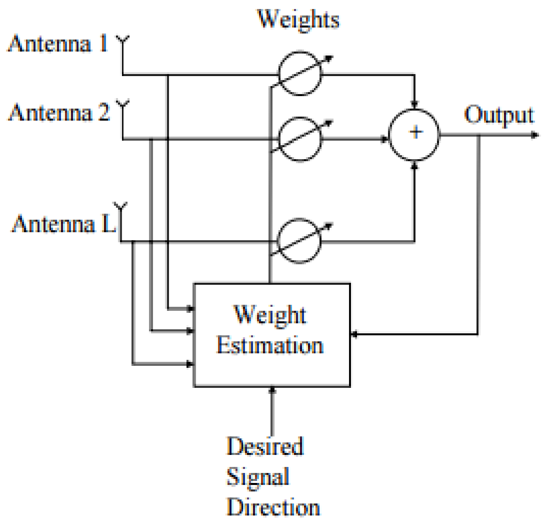

Fig. 1: Block diagram of a conventional analog-based adaptive antenna
Source: [2]

Figure 1 shows a block diagram of a microwave-based adaptive array using digital phase shifters and attenuators. Here, the processor determines new weights based on new inputs to the array. These weights are then translated into the required phase and amplitude for the array elements.

3.3 Modern Digital Signal Processor-Based Architecture

In modern smart antenna structures, digital systems and software are still more dominant. Signals coming to each antenna are digitized independently before being processed in the DSP module. Thus, the cost of adaptive antennas has decreased, and their flexibility has increased. More importantly, all main functions of adaptive antennas have been collected in the digital DSP module, [9].

In this way, it has become easier to combine traditional antenna functions with other techniques. In addition, this approach has created a chance to optimize receiver performance.

Because in the traditional approach, optimizing all subsystems separately does not mean optimizing the whole. An example of this situation is the use of a smart antenna and a delay equalizer together against interference.

The combined antenna equalizer system can cope with large numbers of interferences even if the equalizer is not adaptive. The reason for the decrease in performance of adaptive antennas when used alone is that there are more interference sources than the number of array elements.

Unlike microwave-based systems, weight control in modern smart antennas is done by digital signal processing. Its biggest advantage over traditional systems is the absence of adaptive weighting errors and internal losses observed in phase shifters and attenuators. In addition, DSP-based smart antenna architecture has more flexibility. Furthermore, a DSP-based array can calibrate system errors caused by fabrication and incorrect part design, [10].

Figure 2 shows the block diagram of a DSP-based smart antenna. The most important information to be learned from this is that the adaptive antenna performs two important signal processing tasks. The first of these is to analyze and process the new input data using a suitable algorithm and to determine new optimum weights. The second task is to multiply the optimum weights by the digital signals coming from the antenna elements. Especially in complex smart antenna architectures, two DSP modules working in parallel can be used to perform two tasks and to manage the data more effectively.

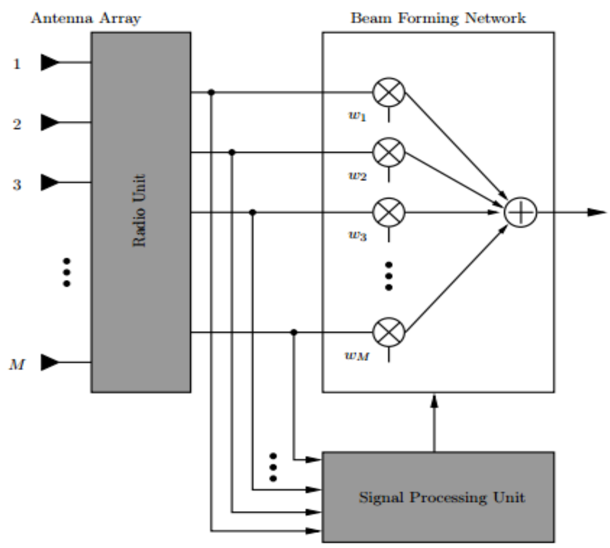

Fig. 2: Block diagram of DSP-based smart antenna
Source: [10]

4 Advantages and Limitations of Smart Antenna Systems

Since smart antennas use a narrow beam pattern to reach the desired user, their gain is higher compared to omnidirectional antenna systems using the same power. This high gain increases both the access distance and the coverage area of the base station used, [11]. Therefore, the number of base stations to be used in a certain area is reduced.

In cellular communication systems, the available frequency channels are divided into different groups, and a frequency channel is allocated to each cell. Some cells in the system use the same frequency channel, [9], [12]. When users sharing the same frequency in different cells use the channel at the same time, the interference to each other is defined as co-channel interference. Co-channel interference limits the system capacity. Smart antenna systems greatly reduce co-channel interferences thanks to their spatial filtering features that focus the radiated power in the direction of the target user in the form of a narrow beam pattern and minimize it in the directions of other users, [13].

Smart antennas reduce co-channel interference and increase the frequency reuse factor. Thus, they provide significant capacity increases by allocating the same frequency spectrum to multiple users at the same time. Omnidirectional antennas distribute energy equally in all directions to reach any user, but reach the desired user with a small portion of the power and cause power to be wasted in unwanted directions (other directions), [14]. Since smart antennas focus energy only in the direction of the desired user, less power is needed to transmit the signal at the base station. This power reduction also reduces interference to other users.

Since signals can be spatially separated into different planes in systems using smart antennas, it increases spectral efficiency when used with any medium access mechanism (FDMA, TDMA, CDMA) and enables more efficient use of the wireless medium, [9]. Multipath propagation signals have different phase angles since they come to the base station from different paths. Since smart antenna systems can adjust themselves to the signal environment, they either reject these signals or use them in a way that increases the signal quality, depending on whether the reflected signals are delayed copies of SOI (signal–of–interest) or SNOI (signal–not–of–interest) signals.

Smart antennas that use multipath signals in this way increase the system performance. Propagation delay is the arrival of the desired signal to the receiver in different directions in a multipath propagation environment, and the delayed acquisition of these signals at different times due to different distances, [13]. Smart antennas prevent multipath propagation and therefore propagation delay due to their features of focusing the beam pattern to certain points and creating empty surfaces without a beam pattern at other points. Smart antenna technologies can be used with many wireless media mechanisms, such as FDMA, TDMA, and CDMA, and can also be used in most modulation techniques, bandwidths, and frequencies.

In addition to the advantages explained above, smart antenna systems also have some important disadvantages. Smart antenna transceivers have a very complex structure compared to the classical base station transceivers. They require a separate transceiver unit for each antenna element, and each of these must be adjusted very precisely in real time, [7]. Since the beamforming process involves very intensive mathematical operations, smart antenna systems require very powerful digital signal processors and control systems. Accordingly, their costs are high.

The main purpose of this study is to examine smart antenna systems and to be able to detect the direction or location of a moving object without using any wireless environment by using the antenna application prepared in this context.

5 Design and Simulation of Moving Object Tracking Application Using Smart Antenna

The software called CST Microwave Studio was used in the design of the smart antenna. Then, according to the simulation results, the final version was adapted and positioned in the system where the application will be made. The designed smart antenna was designed and implemented to have the features and performance to operate in the ISM band 1.1 GHz frequency band. The antenna performance parameters are given in Table 1, the smart antenna CST simulation in Figure 3, and the designed smart antenna structure in Figure 4.

Table 1. Antenna performance parameters

f_r (GHz)	1.1
S_{11}(dB)	-20.512
Dimension (mm)	50-50
Feed Type	Coaxial Line
Bandwidth (MHz)	450
HPBW	52.3^{0}

Source: Calculated by the authors.

Fig. 3: Antenna CST simulation
Source: Drawn by the authors

Fig. 4: Designed smart antenna structure
Source: Photographed by the authors.

6 Simulation Results

The simulation results related to the design are given below. The basic performance parameters of this antenna are given as antenna gain Figure 5, radiation pattern Figure 6, far field radiation Figure 7, and S-parameters Figure 8 and Figure 9.

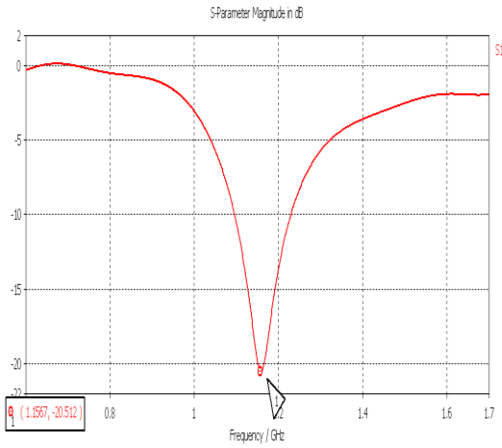

Fig. 5: Gain graph of the antenna
Source: Measured by the authors.

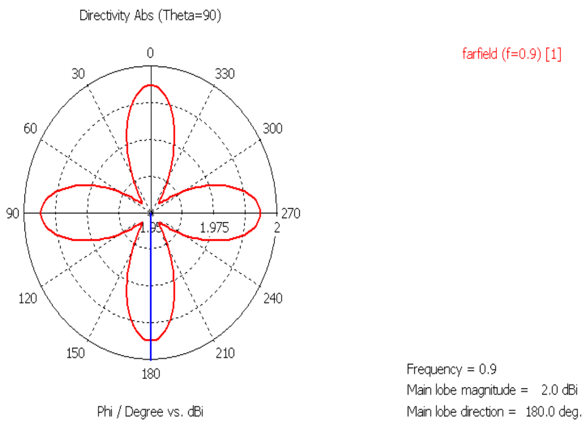

Fig. 6: Radiation pattern of the antenna
Source: Simulated by the authors.

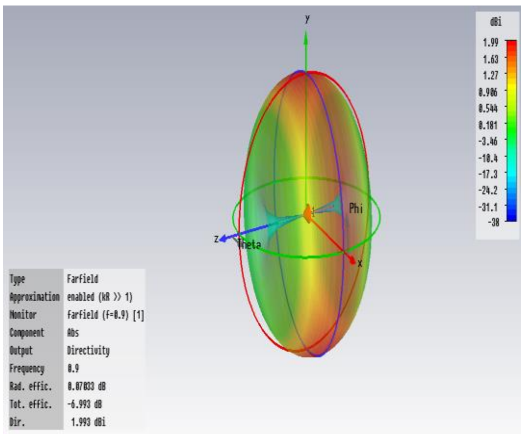

Fig. 7: Far-field radiation of the antenna
Source: Simulated by the authors.

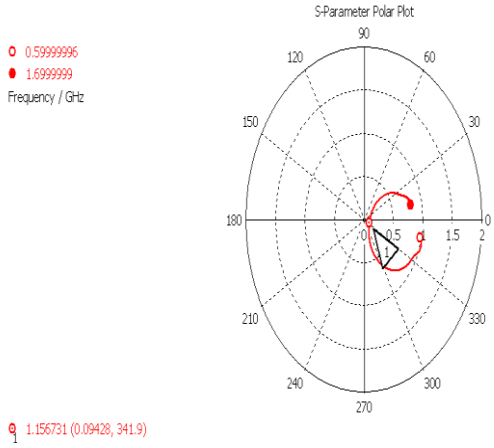

Fig. 8: S parameters in polar form
Source: Simulated by the authors.

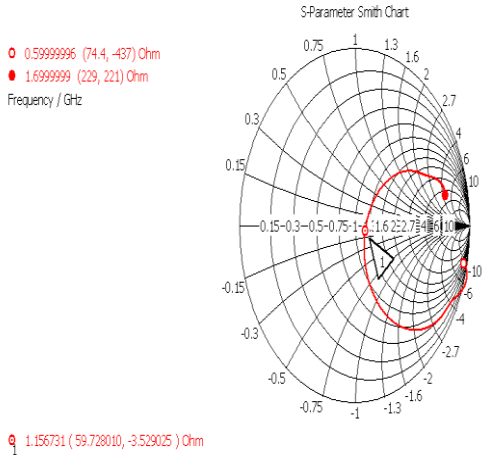

Fig. 9: S parameters Smith chart
Source: Simulated by the authors.

The electric field and magnetic field information of the antenna is as in Figure 10 and Figure 11. Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

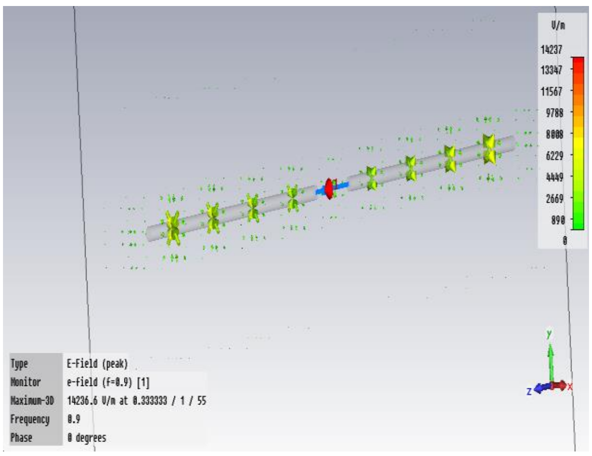

Fig. 10: Electric field value of the antenna
Source: Simulated by the authors.

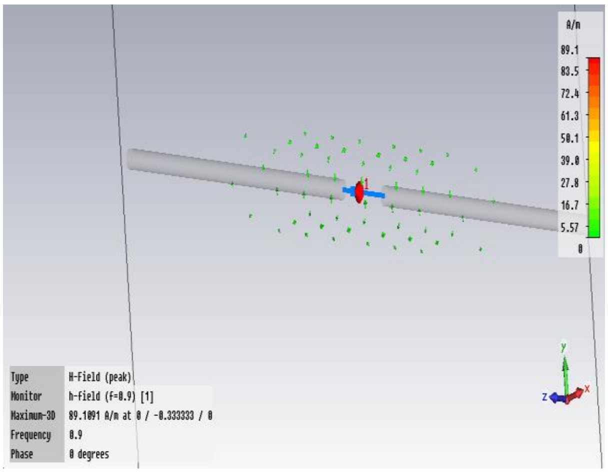

Fig. 11: Magnetic field of the antenna
Source: Simulated by the authors.

7 Laboratory Measurement Results of the Designed System

Within the scope of this study, the designed antennas, RF switch stage, LTC 5509 power detector stage, and microprocessor section were combined, and an outer sheath was created in a suitable geometry. First of all, direction determination operations were performed in the circuit designed with the help of the transmitter. The transmitter, which was set to around 900 MHz, was positioned in the system and numbered, and which of the antennas was the most active was determined depending on the location of the transmitter.

Direction information was obtained according to the program transferred to the microprocessor, and the active and passive status of the LEDs were placed according to the binary system. The program written in the PIC was matched with the antennas assigned according to the directions, some of which are the information of 2- 3- 4 -5, which are their equivalents in the binary system, according to the operating status of the LEDs. Direction determination operations were performed by looking at this information, Figure 12, Figure 13, Figure 14, and Figure 15. Considering the page plane, 2-4-3-5 or information was assigned to the antennas in the east, west, north, and south directions, respectively, and the information of where the transmitter is was obtained.


Fig. 12: Two data and transmitter in the east direction
Source: Photographed by the authors.

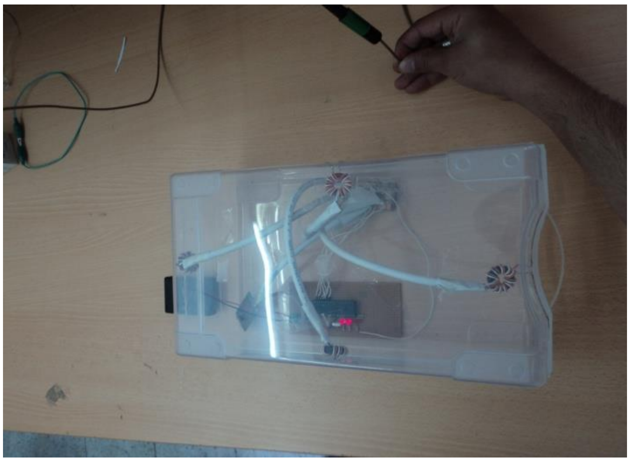
Fig. 13: Three information and transmitter north direction
Source: Photographed by the authors.


Fig. 14: Fourth information and transmitter in the west direction
Source: Photographed by the authors.

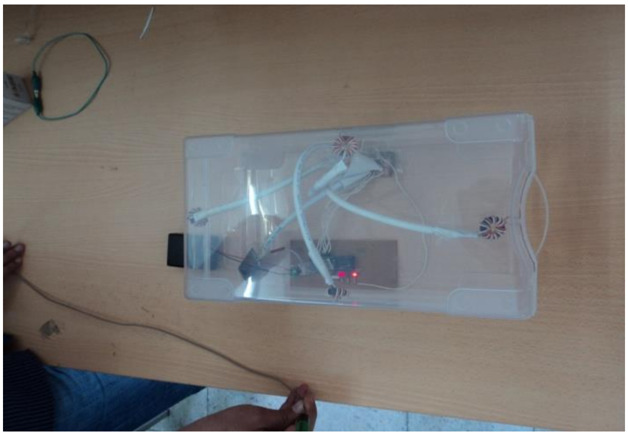

Fig. 15: Five information and transmitter in the south direction
Source: Photographed by the authors.

After the transmitter direction determination process, the voltage values at the output of the LTC 5509 power detector stage were measured directionally, and it was observed that different voltage value results were obtained. The main reason for the different voltage values at the output of the LTC 5509 power detector in these measurements is that the radiation patterns of the antennas are within each other's influence areas. In addition, not being able to provide equal distance and location completely, and the interferences originating from the laboratory environment, cause different voltage values.

8 Conclusions

In this study, it is aimed to determine the direction of a moving object is determined by designing a smart antenna, and a system design is implemented for this purpose. The designed system operates at frequencies of 0.8-1.6 GHz in the ISM band. It has been observed that the location of the transmitter in different directions is detected in the system. The elements of the RF switch, LTC 5509, and antenna stages in the system have been examined to give the best results, antenna simulations have been made, and baluns have been prepared and designed in a suitable geometry. Laboratory results show that the location information in any direction can be determined directionally without satellite internet or a wireless environment, thanks to the designed system. It has been concluded that different voltage values are taken according to the directional measurements at the power detector output in the system; the reason for this difference is that the radiation patterns of the antennas create interference with each other.

It has also been observed that the transmitter distance, frequency, and power values cause changes in the output voltage and affect the performance of the device. Today, the increasing demand for wireless communication technologies and networks has led to the emergence of a need for high bandwidth. This situation has led to a significant increase in the studies on wireless medium access and control protocols. In order to meet the increasing bandwidth and capacity demands, it is aimed to make the medium access and control protocols more useful by using smart antenna systems. Smart antennas: While increasing the signal quality, suppress interference and noise. They also provide power saving. By using wireless medium resources effectively, they increase the system capacity and performance. As seen in this study, smart antennas make the use of the wireless medium more efficient and aim to meet the bandwidth demands of increasing wireless users.

The author(s) contributed to the present research at all stages from the formulation of the problem to the final findings and solution.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

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Conflicts of Interest

The author(s) declare no potential conflicts of interest concerning the research, authorship, or publication of this article.