

A Novel Method to Increase Transmission Power Efficiency in Portable Systems

Chahat Deep Singh¹, B. Sridhar¹Graduate, Department of Electronics & Communication, Bharati Vidyapeeth's College of Engineering, New Delhi, India¹

chahatdeepsingh@gmail.com | bsridhar1993@gmail.com

ABSTRACT: In typical mid and long range transmission systems, the antenna deployed is omnidirectional in most cases. It leads in huge amount of transmission power loss. In this paper, the authors developed a system with an array of directional antennas which are autonomously controlled in order to save the transmission power required in one to one communication. The direction of antenna is changed on change in transmitter/receiver's location. It is implemented using a combination of directional antenna and low power Inertial Measurement Unit (IMU). Using complementary filters with an inertial measurement unit, one can sense the change in displacement, velocity and acceleration of receiving unit. Based on the readings, the current location of the receiving unit can be depicted. Thus, the antenna's direction can be controlled electrically depending upon the location of the receiving unit. This whole system was implemented using an 8-bit microcontroller. The hardware validation and radiation patterns and simulation shows that the system is simple, yet a low power and an effective method to transmit signals for portable systems.

KEYWORDS: Inset-fed antenna, Inertial Measurement Unit, Complementary filter, Rectangular Microstrip patch antenna (*RMPA*), Beam-width.

I. INTRODUCTION

Antennas play a vital role in the field of wireless communications. An antenna is a passive device which does not offer any added power to the signal. Instead it redirects the energy it receives from the other transmitter. An antenna provides 3 fundamental properties to wireless communication system namely Gain, Directivity (Front to Back Ratio) and Polarization. Gain is a measure of increase in energy of RF signal. Direction determines the angle of radiation and shape of transmission pattern, which usually decreases with increasing gain. These angles are measured in terms of beamwidth, which is a measure of angular separation between half power points (3-dB points) in the radiation pattern of antenna. They are broadly categorized as omnidirectional and Directional. Omnidirectional antennas like half-wave dipole and Quarter-wave monopole radiates equal power in all direction which ultimately leads to power wastage and loss of directionality. Poor coverage below antenna is one of the main drawbacks of omnidirectional antenna. Directional antennas like *Yagi-uda*, *Horn*, *Parabolic*, *Helical*, *Patch* antennas directs energy only in single direction and less energy in other directions which is much more power efficient and has high Front to back ratio. Hence to remove these drawbacks of omnidirectional antenna, one opts for directional antennas.

Microstrip Patch antenna plays a significant role in today's wireless communications. Ease of manufacturing, low cost fabrication, efficient radiators, support for both linear and circular polarization and ease of integration with microwave integrated circuits, feed line flexibility are some advantages that makes them find place in almost all simplest and demanding applications [1]. Microstrip antennas are versatile and can be used to synthesize a required radiation pattern. One such directive antenna which provide high front to back ratio with reasonable power efficiency and all the above advantages is an Inset-fed rectangular microstrip antenna.

Paper is organized as follows. Section II delineates the background, the basic design of the proposed system by describing different elements of the each unit. Whereas the Section III depicts the implementation and algorithms that were carried out in order to successfully execute the system. Section IV shows the experimental analysis of the prototype using *HFSS* software. Finally, Section V presents conclusion and future scope.

II. METHODOLOGY

The system comprises of a moving receiving unit (System A) and a transmitter (System B), each embedded with a microcontroller and a pair of antennas- omnidirectional and an array of directional antenna. System B is main transmitting unit and transmits high power signals to the System A. System A is embedded with an *Atmega 328p* microcontroller, a low power 8-bit transmitter (*with omnidirectional antenna*), an *Inertial Measurement Unit (IMU)* and *n* number of patch antennas (*directional*). The *IMU* detects the change in the location in *x, y and z* directions. The change in aspects of all three directions is processed in the microcontroller. This position of the system A is processed in 328p using *IMU* and the positional data is thus transmitted to the 32U4 microcontroller (System B) via the low power omnidirectional 8-bit transmitter. Now, both 328p and 32U4 selects the particular patch antenna based on system A's location. Hence, the power signals are transmitted via system B. *Fig.1* shows basic structure of the receiving unit.

The system B is embedded with an *Atmega 32U4* microcontroller that is responsible for the algorithm processing in stationary transmitting unit. It comprises of a low power 8-bit RF module (*with omnidirectional antenna*) of 2.4GHz frequency. It is responsible for the reception of the System A's positional data. The microcontroller is attached to its main system which is used to transmit high power signals to the system A. To minimize the power, an antenna is selected depending upon the location of the system A. There are *n* number of patch antennas (*directional*) -all having different orientation but same configuration. As the receiver moves from one location to another, a suitable patch antenna is selected (electrically controlled selection) so as to minimize the transmission power. *Fig.2* shows basic structure of the transmitter. (To avoid any confusion, it must be comprehended that System A sends the positional information and receives the power signal whereas System B works antithetically in communication.)

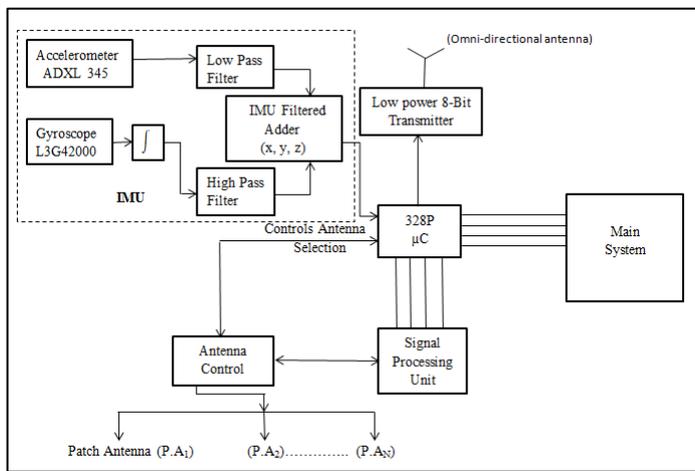


Fig.1 System A (Receiving Unit)

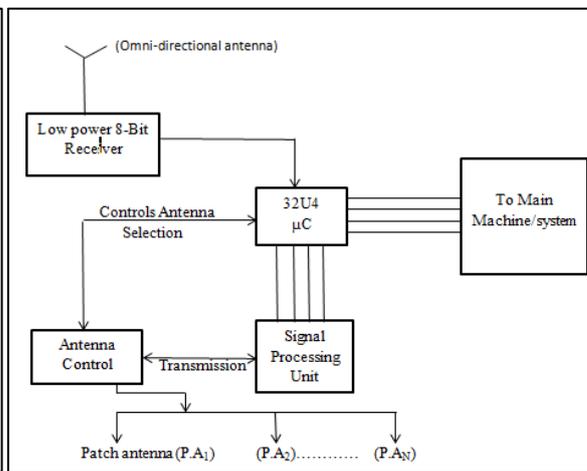


Fig.2 System B (Transmitting Unit)

A. Antenna Design:

Antenna specifications are vital in order to save maximum amount of power. For one to one medium and long range communications, if an omnidirectional is used, then the power is dissipated all over the area. A huge amount of power is lost. Since, in a moving system, the receiving unit rotates around the transmitting section, the signals transmitted to the receiver unit should be at maximum power (or near maximum power) at every angular position. So, to maintain near maximum power transmission at every position with directional antenna, we need to track the position of the receiving unit and hence change the direction of antennas electrically. This can be accomplished using a low-power Inertial Measurement Unit or a GPS system. The detection part will be discussed later in section II.B.

So in order to implement the proposed system, let us first look upon few of the directional antennas. In Patch antennas, Probe-fed, Edge-fed and Inset-fed antennas are widely used for multi range purposes. These antennas can be rectangular, elliptical or even arbitrary shaped. Also, horn antennas, slot antennas, monopole and dipole antennas are widely used for

the same purposes but are very difficult to deploy on a small scale device. The input impedance of these antennas varies according to the geometrical shape, the physical properties of the materials involved, dimensions, the feed point type and its location [2]. These parameters are varied accordingly in order to achieve optimal performance with "best geometry". The rectangular patch is the most commonly employed microstrip patch, which is approximately a one-half wavelength long section of rectangular microstrip transmission line. Let us look upon Inset-fed patch antennas in order to visualize the implementation.

The inset-fed rectangular microstrip antenna is the one consisting of three geometrical regions namely the actual patch region, feed line and ground plane. It provides a method of impedance control with a planar feed configuration [3]. In a rectangular inset-fed patch antenna, the current is low at the ends of a half-wave patch and increases in magnitude towards the centre. Therefore, if the feed is closer to the centre of the patch then impedance will get reduced. The rectangular inset-fed patch antenna is placed in a parallel array as shown in fig. 5, (only one is connected at a time). In fig.5, a total of six patch antennas were placed in parallel, each with 60° of angular displacement. We'll understand more about number of antennas used in section III.

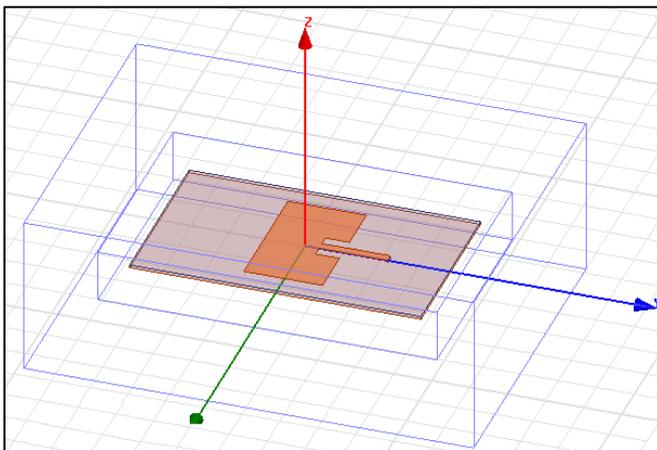


Fig. 4 Rectangular Inset-fed Antenna using HFSS

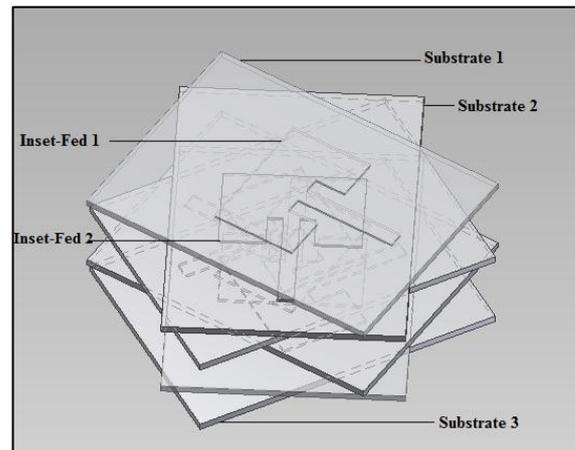


Fig.5 Array of parallel Inset-fed Antennas (3D view)

B. Location Tracking

An *Inertial Measurement Unit (IMU)* with 6 degree of freedom: ADXL345 accelerometer and ITG3200 gyroscope is required in order to detect the change in location. As discussed above, the motion of system A is inferred via the *IMU* and the raw values are processed in the 328p microcontroller. Fig.1 shows the System A and elucidates how the *IMU* is implemented with microcontroller. The *IMU* uses I²C [4] (Inter-integrated circuit) communication in order to communicate with the microcontroller. It is a multi-master multi-slave communication method by which multiple devices can communicate using only two pins: *SDA* (Data) & *SCL* (Clock). A complementary filter [5] [6] [7] [8] was designed to filter the raw values received from accelerometer and gyroscope. The raw values of accelerometer are passed through a low pass filter while the values of gyroscope are integrated and passed through a high pass filter. The filtered values are added in order to generate smooth and filtered *IMU* values.

In order to depict the *velocity* of the system, integration of the *acceleration* vector is necessary (can be calculated using accelerometer) *i.e.*

$$\vec{v}_k = \int \vec{a}_k \cdot dt$$

Also, for location of the system in *x*, *y* and *z*, the integration of velocity vector is essential *i.e.*

$$\vec{x}_k = \int \vec{v}_k \cdot dt = \iint \vec{a}_k \cdot dt$$

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Since, in practice, the data is obtained at discrete time intervals, the *velocity* can be estimated using

$$x_k[i + 1] = x_k[i] + Tv_k[i]$$

where x_k is the position, v_k is the velocity, a_k is the acceleration vector, T is the sampling period & $i \in x, y$ & z .



Fig. 6 Locomotion of System A on a Random Path

The *fig.6* depicts the random path of the moving device (let's say from \vec{a}_1 to \vec{a}_2 on $y = f(x)$) where O is the stationary point where system B is deployed which transmits the power signals. Now, from the figure, in triangle $O\vec{a}_1\vec{a}_2$, we can say that:

$$\theta = \varphi - \phi \tag{i}$$

Also, the angle intercepted at origin between the two points: \vec{a}_1 and \vec{a}_2 be θ and can be simply given by:

$$\theta = \cos^{-1} \left(\frac{\vec{a}_1 \cdot \vec{a}_2}{|\vec{a}_1||\vec{a}_2|} \right) \tag{ii}$$

$$\phi = \tan^{-1} \left(\frac{\vec{a}_1 \cdot \hat{j}}{\vec{a}_1 \cdot \hat{i}} \right) \tag{iii}$$

Hence, using (i), (ii) & (iii), we have

$$\varphi = \tan^{-1} \left(\frac{\vec{a}_1 \cdot \hat{j}}{\vec{a}_1 \cdot \hat{i}} \right) + \cos^{-1} \left(\frac{\vec{a}_1 \cdot \vec{a}_2}{|\vec{a}_1||\vec{a}_2|} \right) \tag{iv}$$

On the movement of system A, the angle can be deduced by 328p using *IMU*. The new location is transmitted to system B via omnidirectional antenna. Now, the microcontrollers- 328p and 32U4 selects their respective directional patch antenna depending on the location of the system A. The process is carry forward everytime system A changes its location. Recapitulating, the change in angle intercepted System A is θ . So, depending on θ , the suitable patch antenna is selected.

III. IMPLEMENTATION

As discussed earlier, *Fig 6* shows the abstract diagram of the entire system having System B positioned at origin O and system A moving in a random path. All the Essential components inside System A and System B have been explained in the earlier section. Let us discuss about the protocols and transmission power of the two systems. There has to be some communication protocol that both the system agrees to. Therefore, System A will initiate the wireless communication process by sending its new angular positional data to System B via a low power 8-bit transmitter. *IMU* detects the new position or change of location in x, y and z directions of the System A. The new positional data is sent to the System B via a low power 8-bit transmitter. This new positional data is also sent to an *Atmega 328p* microcontroller by *IMU*. Now, indirectly, this microcontroller is responsible for the selection of the suitable patch antenna from an array of parallel antennas. *Fig. 5* shows the 3D diagram of the antenna network. System B will receive the transmitted new positional data of System A via a low power 8-bit receiver. The receiver will send this data to an *Atmega 32U4* microcontroller, which will responsible of selection of particular patch antenna out of n such number of antenna of same configuration. Since the system A rotates around the System B, the signal strength of the transmitted signals by patch

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antenna of System B to the patch antenna of System A may vary if the suitable antenna is not selected. Depending upon the power radiation of each antenna and the location of the system A, a pair of patch antenna (each from system A and system B) must be selected so as to transmit the signals with maximum power (or near maximum power) at every position. After the required transmission and reception of signal from directional antenna of System A to the System B respectively, the signal will get stored inside the Main system.

In telecommunication, half power beamwidth is the angle between half-power (3-dB) points of the main lobe when referenced to the peak effective radiated power of the main lobe [9]. Fig.9 shows the radiation pattern of a single patch antenna. According to this figure, the beam-width comes out to be approximately 56° . Since angular position of System A is changing, hence orientation of directional patch antennas in both system should also be changed in such a way so as to get maximum power at any particular angular position A. This can be achieved by using an parallel array of antennas in both the System oriented in such way that a particular patch antenna will get activated in both the System A and System B depending upon the location of System A.

Here, beam-width calculated came out to be 56° . Since System A is moving randomly, its angular position could be anywhere between -180° to $+180^\circ$. Hence we need a minimum of 6 such patch antennas ($360^\circ/56^\circ \approx 6.42$) in both the System with an angle displacement of 60° among each of them. Depending on the angular position of System A, activation of particular antenna in both the system will take place. Fig 5 Shows the arrangement of parallel inset fed antennas in both the systems. According to this arrangement, antennas must be selected in Anti-symmetric fashion in both the system so as to get a maximum or near maximum power for a particular location of System A in between -180° to 180° . Table.1 shows all the cases of locations of system A and which set of antennas in both the system to be activated for a particular location of System A.

Angular Position of System A (φ)	Activated Patch Antenna(Sys A)	Activated Patch Antenna(Sys B)
-30° to $+30^\circ$	1	4
$+30^\circ$ to $+90^\circ$	2	5
$+90^\circ$ to $+150^\circ$	3	6
$+150^\circ$ to -150°	4	1
-150° to -90°	5	2
-90° to -30°	6	3

Table 1: Look-up Table for Activated Antennas

For maximum efficiency, the antenna with the power lobe concentrated at the location (or closest to the location) must be selected. So, the array of antenna must be designed carefully. Also, input impedance of these varies with geometrical shape of antenna, physical properties of material, feed type and its location. Therefore, certain parameters are needed to be varied so as to get the “best geometry” at the particular operating frequency. So, the designing of such directional antenna was implemented using HFSS simulation software. Fig. 6 shows the design of an Inset-fed rectangular patch antenna with all the parameters labelled on it. This design of patch antenna assumes that the specified information includes the dielectric constant of the substrate (ϵ_r) and the thickness of the substrate that provide a good impedance match for inset-feed patch structure [10]. Table 3 shows some of the important design parameters of inset fed patch antenna using HFSS [11]. Some of the important design parameters for inset-fed rectangular patch antenna are given in the Table 2 and Table 3.

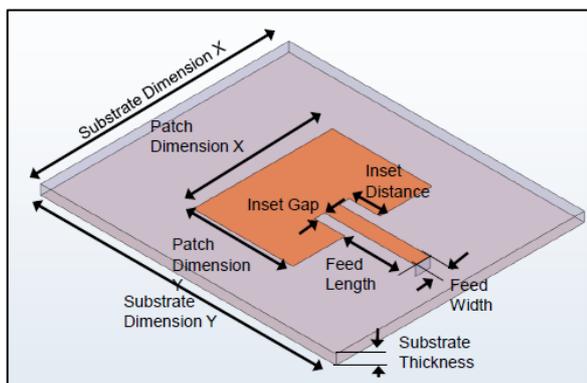


Fig. 7 Inset-Fed Rectangular Patch Antenna

Parameters	Length(cm)
1. Patch Dimension Along x (W_p)	4.94
2. Patch Dimension Along y (L)	3.175
3. Substrate Dimension Along x	9.4
4. Substrate Dimension Along y	15.34
5. Inset Distance	1.263
6. Inset Gap	0.543
7. Feed Width	0.485
8. Feed Length	3.807
9. Substrate Thickness (h)	62 mil

Table 2: Simulation Design parameters using HFSS

Design parameter	Values	Design parameter	Values
Dielectric constant ϵ_r	2.2	Extension length ΔL	0.56cm
Frequency f_0	2.4×10^9 GHz	Effective length L_{eff}	4.3cm
Velocity of light v_0	3×10^8 m/sec	Effective ϵ_{reff}	2.11
Loss Tangent ($\tan\delta$)	0.0009	Relative permeability	1

Table 3: Design parameters of patch antenna

IV. RESULTS

As discussed in the above section, an antenna is implemented meticulously based on the requirements. Fig.8 and fig. 9 show the radiation pattern in 2D and 3D respectively. It can be noted that, the transmission power is concentrated in about 60° of angular displacement. Unlike omnidirectional antennas, a considerable percentage of power loss is reduced. Since, the system A is mobile object, the antennas needs to change the direction. The switching was done electrically rather than mechanically so as to save the power in switching mechanism.

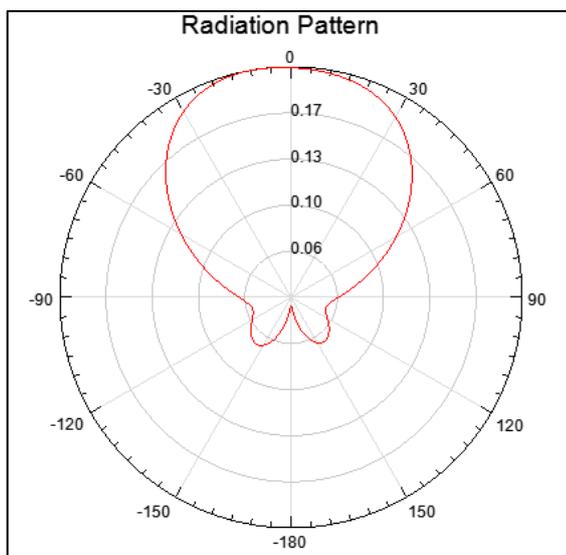


Fig. 8 Radiation Pattern of Designed Patch Antenna

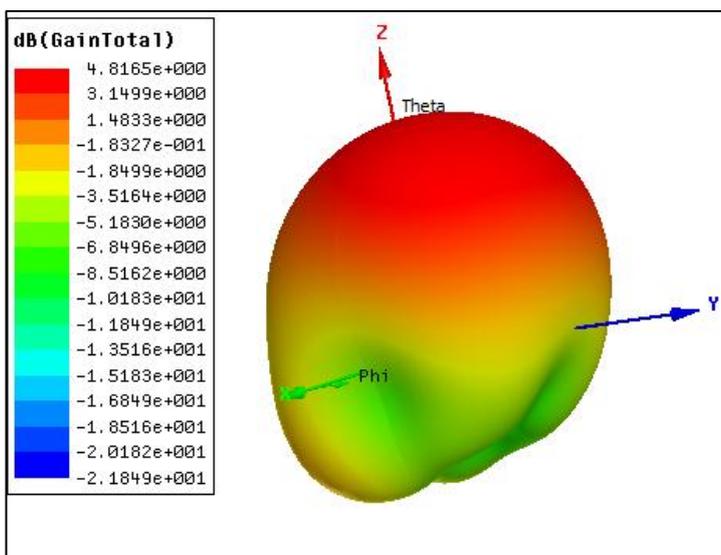


Fig. 9 Three Dimensional Radiation Pattern

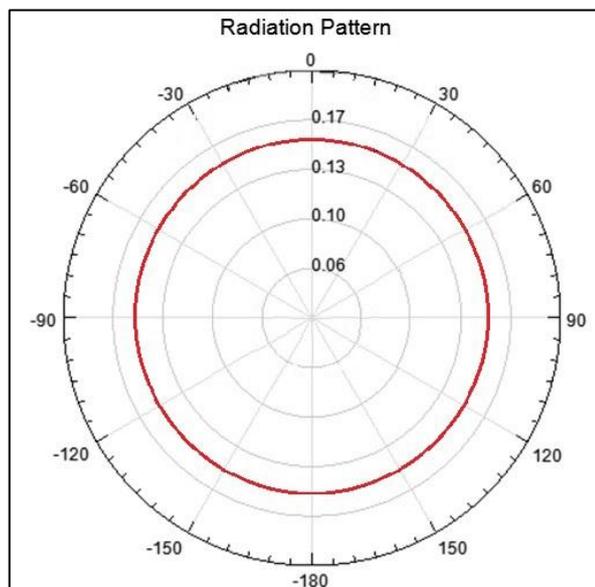


Fig.10 Radiation Pattern of Omnidirectional Antenna

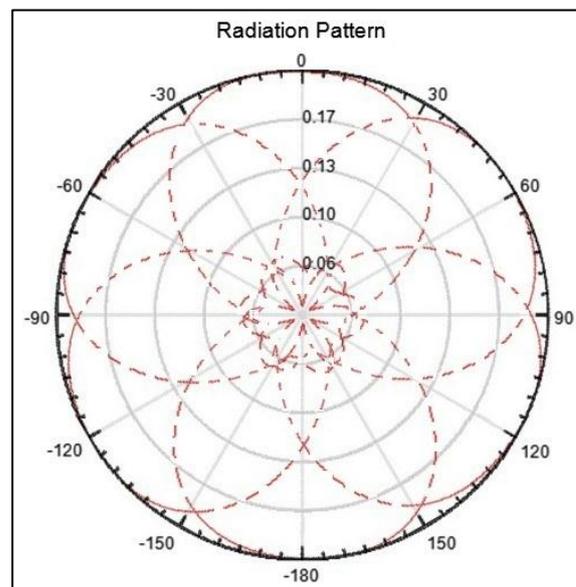


Fig. 11 Radiation Pattern of 6 Inset Patch Antenna combined

Fig. 10 depicts the radiation pattern of a similar size omnidirectional antenna. Also, fig. 11 shows radiation pattern of the patch antenna array. The suitable patch antenna is selected in order to maximize the efficiency and thus reducing the transmission power. It should be noted that the out contour of the radiation pattern in the fig. 11 is much more than fig. 10. The two radiation patterns confirm that the power saved in transmission in one to one communication in mobile objects is of considerable amount.

V. CONCLUSION AND FUTURE SCOPE

The system is light weighted and a valuable addition to any existing transmission system. Depending upon the locomotion, average radius and signal rate, the power transmission may vary abruptly. Also, to minimize the power required in sharing the positional information, a low power 8-bit transmitter receiver system was very useful. Further, depending upon the range and selectivity, the antenna can be designed distinctly. The number of antennas in an array may vary as well. With the increase in number of antenna in an array, the efficiency of the system will increase. As the number of antennas approaches infinity, the radiation pattern forms a circular shape. It will thus work as an omnidirectional antenna with power required only of directional antenna (of similar magnitude). Furthermore, the system can be deployed in other systems and applications like Radio/ TV signal transmissions, walkie-talkies, aircrafts, submarines/ships and other military purposes.

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BIOGRAPHY



Chahat Deep Singh graduated from Bharati Vidyapeeth's College of Engineering, New Delhi in the department of Electronics & Communication. He has worked in the fields of embedded systems, robotics and control algorithms under experienced supervision. He has developed a number of distinct prototypes and systems in various fields.



B. Sridhar graduated from Bharati Vidyapeeth's College of Engineering, New Delhi in the department of Electronics & Communication. His fields of interests are high frequency applications in optical communication, planar antennas, and applied electromagnetics. He has co-authored publication in some of these topics in international journals.