Design and Characterization of Downlink Patch Antenna for DS-CDMA Based Mobile Communication Applications

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***Abstract*—The third and fourth generation communications require increased bandwidth for its hassle free data transfer and communication without interruptions. The quantum of data transfer is huge and is ever increasing furthermore. Thus, there is a need for an antennae system of higher efficiency to facilitate data transfer at high speed. This paper is focused on to develop a patch antenna to form a highly directional beam to maximize the power transfer for DS-CDMA wireless communication for mobile applications. The patch antenna is optimized by using ADS software. Antenna is designed in such way so the given bandwidth for uplink and downlink is best achieved. An antenna for downlink is designed and subsequently its characteristics are analyzed. A circular polarization is chosen since it is easier to implement and also a less loss is associated with it. A coaxial feeding technique is used to get better impedance matching. The radiation loss, bandwidth, impedance, s-parameters and efficiency parameters are analyzed for performance at a resonance frequency of 2.24 GHz range. The gain achieved is about 7 to 9 dB at efficiency of about 80%. Return loss estimated at -1.423 dB. The analyses of simulated results show radiated power at the rate of 0.25 mW/sterad. The directivity and absolute fields' distributions are good. The patch antenna of these characteristics is expected to be useful for DS-CDMA mobile communication in 4G networks in near future.**

Keyword- Patch Antenna, DS-CDMA, Wireless Mobile Communication, BER, Polarization

I. INTRODUCTION

Optimization for direct sequence code division multiple accesses (DS-CDMA) based mobile communication system has been carried out by using different techniques and strategies by numerous researchers. The techniques vary from software based ones to hardware implementations and quite often intelligent enough to maximize the efficiency under variable conditions. Intelligent and smart antenna systems are developed to meet required bandwidth under 3G communication protocols [1]. Kundu et al [1] has undertaken a research work to design and implement adaptive antenna with use of processor to achieve directional properties which ultimately improved system capacity. Analysis includes users at different power level at different direction of arrival. Digital signal processing is applied to obtain high directional gain. The authors have earlier implemented DS-CDMA system for improved performance by applying ADALINE neural network [2]. The focus was to reduce the BER and also, MAI cancellation was improved thus ultimately channel efficiency improved considerably. In yet another research studies, the smart beam forming was implemented and analyzed for performance parameters with improved throughput for high speed mobile applications [3] [4]. Sanyal et al [5] has shown that if signal processing techniques are used then the directional gain can be improved and it further results in reduced interference in the same direction. This serves multiple benefits for improving system capacity and throughput. These studies and research results indicate that DS-CDMA system has been optimized to a large extent by designing it intelligently. Algorithm based optimization can be good and also at times have drawbacks such as speed and system frequency dependent speed constraints. There are different environments of operations and furthermore quite often contrasting situations arise where tradeoffs are the best options. In those operating conditions, the system can be designed by hardware implementations and additionally optimization can be done using intelligent techniques and adaptive methods. Adaptive methods are quite successful in variable and unpredictable environments [6]. The study for an array of omnidirectional and adaptive antennas was generalized for base station in order to achieve an improved rate control. It resulted in enhanced signal to interference ratio (SINR) which means higher throughput with significantly reduced interference [6].

Authors have implemented another technique for improving the OFDM-CDMA based radio communication by using minimal trellis module. Main parameter for performance measurement BER was used. A reduction in BER up to 10 % was observed [7]. Also it included analysis on flexible rate selection technique for varying channel conditions. It was observed that channel utilization was improved with better efficiency and higher system capacity [7]. CDMA communication system was implemented on FPGA with low complexity and higher speed. The analysis included hardware utilization and higher channel utilization [8].

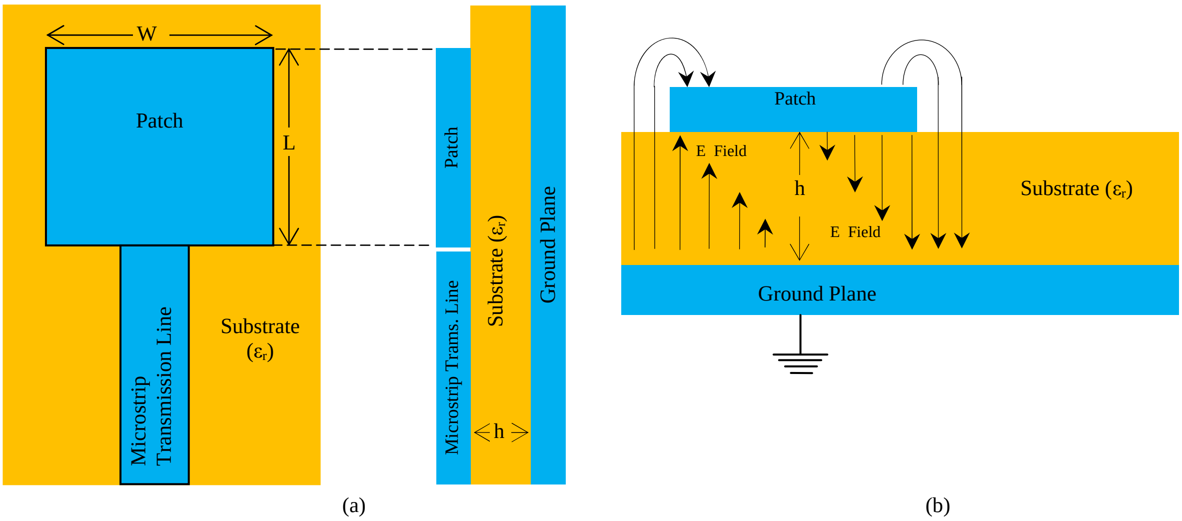


Fig. 1. Geometrical structure of a typical patch antenna (a) various dimensional presentation (b) Electrostatic Field distribution between patches and ground plane across the substrate

The literature analysis shows that the recent studies and research work had hardly given any thought towards design optimization for antenna. DS-CDMA communication system is predominantly used in mobile communications. For mobile communication, the antenna is very critical and an efficient design will result in better efficiency of data flow. The patch antenna is mostly used for handheld compact devices due to small and light weight apart from being power efficient. Thus it is natural choice for the given application. The current work reported in this paper is focused mainly on designing and characterizing the patch antenna for CDMA mobile communications. The paper represents a complete systematic approach to design and then measure the functional parameters for patch antenna. The design for such an antenna system is very challenging as it requires miniaturization apart from being very precise in functional modes as available signal strength may be fluctuating from very low to negligible for mobile devices [9]. Patch antenna has many advantages such as it is light in weight, can be of any shape, incurs low cost and supports circular polarization. A variety of feeding techniques can be used according to the application requirements [9].

This research work is undertaken in the anticipation of frequency requirements for 4G CDMA mobile communication systems in the near future which is predicted to be from 2 to 8 GHz [10]. Currently CDMA communication systems use frequency range below 2 GHz in any case in India. This is likely to be beyond 2 GHz range very soon as next generation mobile networks will need increased capacity and channels to fulfill the needs of ever increasing users. Normally low frequency is suitable for long range but less number of users or in other words less user density. High frequency range is more suitable for short range but for higher number of users in a given region. Keeping this in mind we have proposed a patch antenna for DS-CDMA mobile communication system for the operation in 2.24 GHz range. This range is currently used for small satellite applications such as PICO satellite. However, soon mobile devices will required this range of frequency to maintain the system capacity demand-supply balanced. We predictably propose that DS-CDMA mobile communication will have applications of our antenna for smooth data transfer services. Some networks in India, though very limited, currently use TD-LTE frequency range in 4G applications nearly at 2.3 GHz. This prompted us to design the patch antenna at 2.24 GHz for downlink communications for DS-CDMA based networks.

II. Patch Antenna Design Strategies

Patch antenna looks like a small metallic patch on either sides of any surface where it can easily be mounted permanently. The mounting can be that of depositing of metallic thin or thick film on an insulated material of certain thickness. The insulation base is called as substrate, which is sandwiched in between two metallic surfaces. Substrate provides a physical support as well as it serves as a vital component of the antenna system [11]. The substrate plays an important role in the efficiency and operation of the patch antenna according to its value of dielectric constant and thickness used for the design. It is normal practice to choose the length of the patch in the range of $0.33\ \lambda_0 < \lambda 0 < 0.5\ \lambda_0$ where λ_0 is free space wavelength. The patch may be thin with thickness t less than λ_0. The thickness of substrate may vary in the range of $0.003\ \lambda_0 < h < 0.5\ \lambda_0$ where h is thickness of the substrate. The substrate may be chosen according to the dielectric constant required for a given design application. A typical geometrical structure of a patch antenna is illustrated in Fig. 1 (a) with various dimensional variables labeled clearly. Fig. 1 (b) shows electric field distribution between patch and ground plane and across the substrate. The fringing effects at the edges of patch may cause resonance at specific frequencies [9]. The electrostatic field is constant along the width and its phase changes along the length of the patch as shown in Fig. 1 (b). The normal mode of operation the pattern is TM_{10} mode with no variation along *y*-axis but varies along *x*-axis (L) which is normally kept at half of the wavelength through dielectrics.

A. Design Parameters

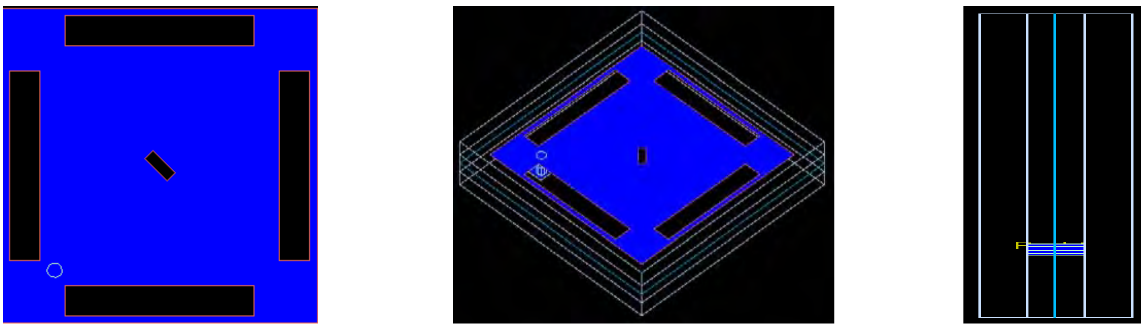
The design of the antenna is done on the Advanced Design System (ADS) platform. The first requirement for a patch antenna is that of theoretical conformity to the physical laws of electromagnetic principles. For this particular design which is CDMA communication system specific, the main design parameters chosen include operating frequency, dielectric constant of specific substrate, feed type, feed position and thickness of the substrate.

The operating frequency is chosen in S-band range for a downlink at about 2.24 GHz. The substrate is chosen on the requirements of dielectric constant at the value of about 2.2, which matched approximately with Rogers RT Duriod 5880. The substrate is very critical for the design as it directly affects width of the patch. The substrate should be stable and physically robust to withstand varying operating environment [12]. Various tradeoffs are made for the selection of substrate and feeding techniques. The first constraint comes from fringing effects. As the length of the patch increases, the fringing effect is also increased. Impedance matching suffers an inductive shift due to increase in inductance associated with coaxial cable [13]. The bandwidth slightly increases with height h of the substrate, however, the directivity improves by a small margin with h due to increase in effective aperture area. The design includes a substrate of thickness h = 1.532 mm. The antenna efficiency increases with substrate height initially due to higher radiated power but soon it deteriorates as cross-polar increases. This could also be due to surface waves [14]. Taking all of these factors into account, the above mentioned substrate material type is chosen.

B. Effects of Dielectric Constant, Ground Plane and Feeding Technique

The design parameters of resonance frequency, efficiency, bandwidth and patch dimensions are subjected to the value of the dielectric constant of the substrate material used for the design of patch antenna. The bandwidth of the antenna increases with decreasing dielectric constant. Ideally a ground plane should be infinite in dimensions. In practice, if the ratio of ground plane to patch size is about 6 or higher, then the antenna approximately behaves as if it had infinite size of ground plane.

There are variety of feeding techniques available for selection for a given design requirements and constraints. These include co-axial feed and microstrip feed. This research work is focused on the co-axial feed which is also known as pin feed. The choice of the feed techniques is based on the facts that pin feed can be easily placed at any point on antenna for impedance matching purpose. The general design structure for the given application of CDMA mobile communication is shown in Fig. 2 with feed position, slot position and different planer and 3D views of patch antenna.



(a) (b) (c)

Fig. 2. Physical antenna design views (a) Top view of 4 slotted structure and feed location, (b) Isometric view of the same patch and (c) cross sectional view illustrating feed position across substrate.

Single feeding technique is easier for implementation but the location of the feed position is to be decided by heuristic methods which are tedious and time consuming. The impedance of a typical coaxial cable is about 50 Ω, which is to be matched by changing location of the feed. Two feeding techniques may need hybrid coupler and thus increased cost. The design of antenna for this research work includes only single coaxial feed for circular polarization.

C. Slotted Design Patch Structures

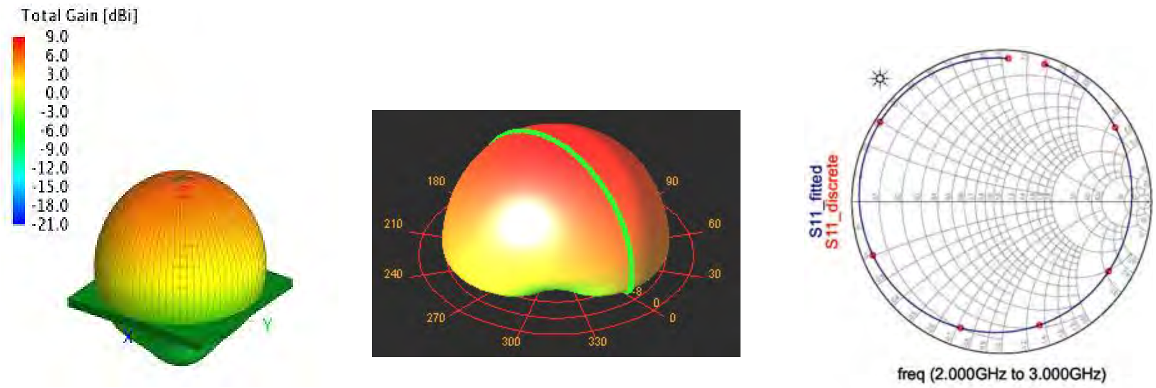
A rectangular patch on the substrate acts as a cavity with radiating edges facing magnetic walls. Magnetic field transverse TM_{100} mode is usually used for practical implementations. The other two modes TM_{200} and TM_{300} are normally not suitable for usages due to radiating currents are grating lobes. A structural detail of a slotted antenna is illustrated in Fig. 2 (a). Two slots are placed near to the radiating edges. Slots may slightly change the resonance frequency compared to one without slots called as standard patch. The currents will flow around the slots to have resonance and null point closer to two edges of slots. With increasing slot length field distribution for central part of patch increases which results in increased broadside direction coverage. This design refers to a slotted square patch by using standard mathematical relationships available in common literature [15].

III. Implementation and Simulation Results

All dimensions of patch antenna are chosen or computed from mathematical models by conforming physical principles and laws of antenna theory [9], [15] to achieve the resonance frequency of about 2.24 GHz. The substrate chosen is Rogers-RT_Duriod 5880 from the library of Advanced Design System software platform. Its dielectric constant is about 2.2, loss tangent D is about 0.0009 with thickness is 1.575 mm. The patch dimensions were arrived at by heuristic and trial methods of computations to be of 41.69 × 41.69 mm. The square pattern was chosen due to the fact that it is particularly suitable for better polarization. Further it can be helpful to optimize the frequency requirements. The substrate size is assumed to be of infinite size under the simulation method of momentum of microwaves technique. The slot size is computed to be of 25 × 4 mm. The centre slot has dimensions of 4.169 × 1.532 mm. A feed position as indicated in Fig. 2 (a) is located at (7, 7) in *x-y* plane. The location of pin feed is computed in such a way that impedance matches at 50 Ω of cable feeding. The simulation tests are carried out using ADS software package. The patch is designed by physical measurements and material selection from library of the software.

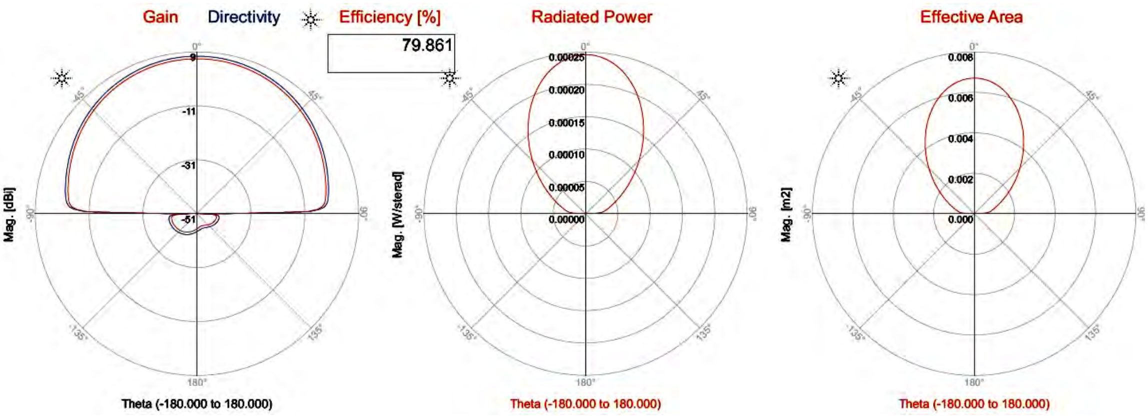
A. Simulation Performance Parameters

The design is then simulated to validate it for the desired performance. The main parameters chosen for performance analysis are radiation patters, gain, return loss and bandwidth for given resonance frequency at 2.24 GHz. Fig. 3 shows the three of the parameters selected for the performance analysis. Fig. 3 (a) shows directivity and gain associated with it in the desired direction. This is indicative representation produced by simulation results. The actual gain varies between 7 to 9 dB as illustrated by Fig. 3 (a), which indicates it clearly. Fig 3 (b) indicates *phi (φ)* model with reference spatial location axis. Fig. 3 (c) shows smith chart representation of the impedance matching. The chart is drawn with frequency range from 2 GHz to 3 GHz as the resonance frequency is desired at 2.24 GHz. The marker has a discontinuity which is associated with Smith chart characteristics. The marker starts at 2 GHz and ends at 3 GHz. The graph is moved clockwise in direction and it falls slightly from the boundary as it moves along. This is due to losses associated with the transmission lines. The transmission line impedance matching occurs at about 50 Ω with unterminated coaxial cable of the same impedance. The graph terminates at constant resistance circle of value 1.

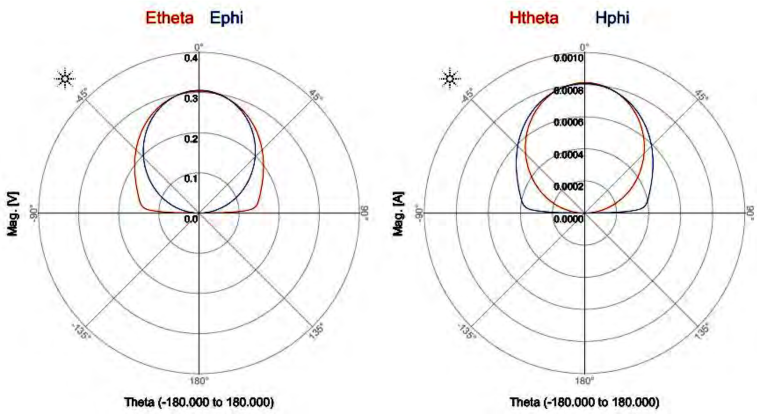


(a) (b) (c)

Fig. 3. Patch antenna performance parameters' visual representation (a) Directivity, gain magnitude and reference direction, (b) *Phi (φ)* model representation (c) Impedance matching representation on Smith chart



(a)



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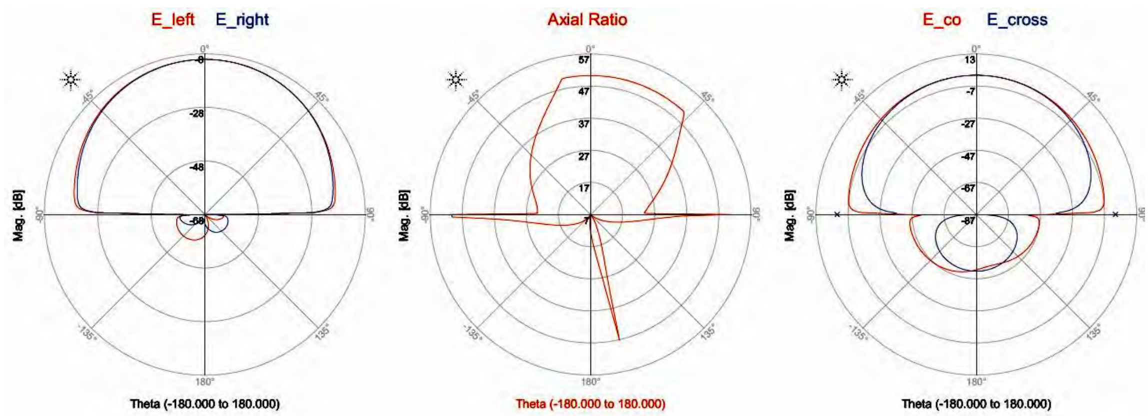
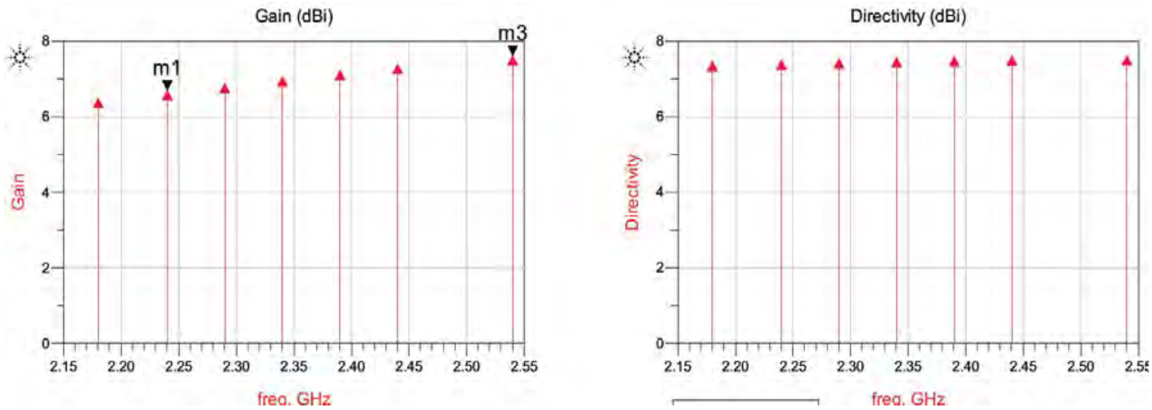


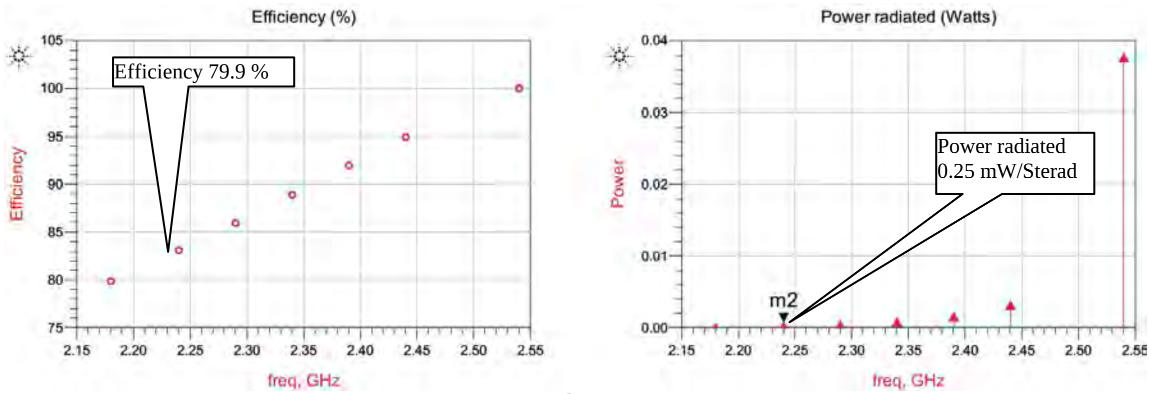
(c)

Fig. 4. Patch antenna performance parameters' visual representation (a) Gain vs. directivity, radiated power and effective area (b) Absolute fields and (c) Circular polarization, axial ratio and linear polarization pattern

The next set of parameters and their values of patch antenna are shown by various graphs indicated in Fig. 4. These include gain in the desired direction, efficiency, radiation power and axial ratio. As shown in Fig. 4(a), the gain is achieved at about 9 dB for a simulation test. The efficiency of the antenna system is around 79.8 % as shown by red line in the same graph. The radiated power was not so good and thus the same design would further focus on improving the radiated power in the near future. The radiated power rate has a mean at 0.25 mW/Sterad. The gain and efficiency are quite high and almost at desired value for the current application of patch antenna. Fig. 4 (a) also shows the effective area in m^2 units. These parameters are maximum in the direction at φ = 0 value. Fig. 4 (b) illustrated with absolute fields for the simulation carried out. Their values and corresponding angles are illustrated in the same figure. Fig 4 (c) clearly indicates polarization patterns and axial ratio which are in conformity with normal range values.



(a)



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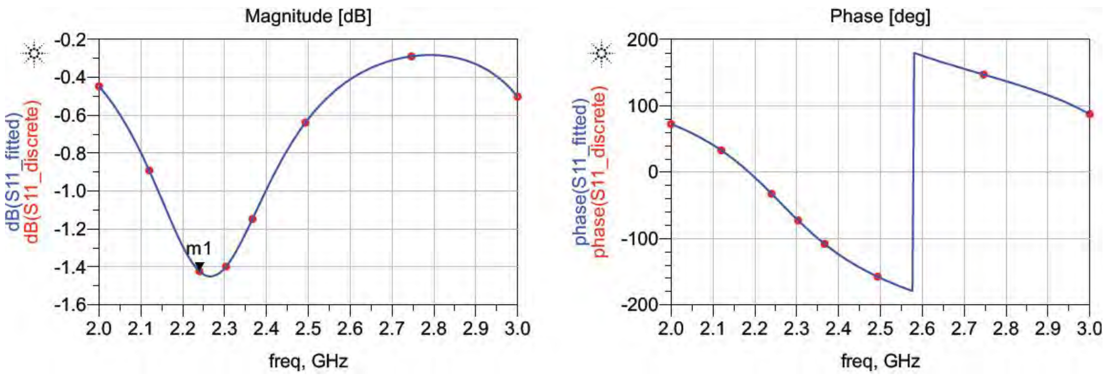

(c)

Fig. 5. Patch antenna performance parameters' visual representation (a) Gain and directivity (b) Efficiency and radiated power rates and (c) Return loss (s_{11} parameter) and phase reversals vs. frequency

Fig. 5 illustrates gain in dB as a function of frequency in bar graphs. The gain is observed during simulation tests at nearly 7 and directivity is at 7.5 dB which are considered to be good enough for the preliminary design to carry on further research. Fig. 5 (b) illustrates efficiency and rate of power radiated. These values are observed at 79.9 % and 0.25 mW/sterad respectively. The main issue remains about the low rate of power radiation. This will need further analysis for the optimization of the design. The efficiency is reasonably good for the first design. Fig. 5 (c) illustrates return loss (parameter S_{11}) which is achieved at about -1.423 dB. The return loss or coefficient of reflection is reasonably optimum and normally accepted at this level. Fig. 5 (c) also indicates phase reversal at resonance frequency which is in conformity with validation of the design. The phase reversal (point of –180^o) takes place slightly above 2.24 GHz range which is to be further optimized for exact value.

IV. Conclusion

We have presented our work related to design and simulation tests carried out for the implementation of patch antenna for DS-CDMA mobile communication systems for down link (transmission from base station to mobile device) frequency band. The antenna designed and tested is expected to find wide applications in 3G and 4G CDMA based mobile communications. The frequency requirements for 3G and 4G are ever increasing continuously and there will be a huge demand furthermore as the number of users are increasing day by day. To keep the demand fulfilled, we need to develop a matching technology on the same scales. In the wake of predictions of CDMA communications frequency requirements to be well beyond 2 GHz, we have responded by designing a patch antenna to be operated at 2.24 GHz frequency for the applications of mobile communications. The substrate Rogers-RT_Duriod 5880 with dielectric constant of 2.2 is used for the patch antenna. A very compact and small central patch of 4.169 × 1.532 mm is designed and tested. The whole package including substrate is of less than 50 × 50 mm in size making it very suitable for compact and mobile device applications. To summarize the test results, the return loss has been achieved at a very low value of -1.423 dB. This is very encouraging result as the levels of return loss at this value are generally accepted. The gain is about 7 to 9 dB, reasonably good enough for the first design, however it could also be improved further. We achieved efficiency at about 80% which is again considered to be good but need to be improved further. The directivity is about 7.7 dB and radiated power rate is in the range of 0.25 mW/sterad. Phase reversal is observed at slightly higher than resonance frequency needing to look for further optimization. Absolute field distributions and axial ratio simulated result analyses are done. The results are approximately in conformity with usual observations available in the published literature.

The future work may be focused on further optimization and study of effects of substrate thickness and types of it. The different substrates of varied dielectric constants are needed to be analyzed for the improvements in gain and efficiency of the antenna system. The main concern is to improve upon rate of radiated power and exact phase reversal which are not very good as per our result analyses. Different types of feeds may be analyzed for better impedance matching. Another area for further research work on the topic may be that of uplink design and dual band design in near future.

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