Mechanically Controlled Smart Corner Reflector Antenna System for Cellular Networks

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***Abstract*--- In this paper, a smart antenna system (switched antenna with adaptive pattern) is realized using Dipole in front of Corner Reflector Antenna (DCRA). The whole antenna pattern is mechanically steered to the directions of interest within the heavy traffic sector, while the antenna pattern is tailored according to the electromagnetic environment. The adaptive pattern is realized by mechanically controlling the DCRA geometrical dimensions. The Corner reflector antenna is designed and simulated using WIPL-D software package. The smartness features of the antenna are examined by varying the DCRA parameters such as dipole spacing, length, width and orientation, reflector angle, and reflector dimensions. The antenna patterns and parameters; specifically directivity and the standing wave ratio; VSWR, are observed for all the cases and the best combination for each case is concluded. The DCRA is designed, analyzed, implemented and measured for base station of GSM 900 cellular networks. The simulated and measured results are compared with the corresponding published results and found satisfactory.**

Indexing Term--- **Cellular networks, smart antennas, corner reflector antenna.**

I. INTRODUCTION

The smart antenna is an intelligent system that senses the radio environment, including both traffic and interference levels. Accordingly, configures its radiation pattern to optimize the radio performance. Smart antennas are emerging as an integral element of the latest generation of wireless communication systems to improve its quality of service. Smart antennas can be applied to both analog and digital communication systems, in wireless local area networks (WLAN), microwave communication and radar systems. Also, the adaptive array signal processing technique is applied to obtain computerized tomography (CT) used in medical diagnosis. Switched beam and adaptive array are the two major categories of smart antennas. Switched or fixed is the simplest one, in which a finite number of predefined patterns are formed in fixed directions. Adaptive approach has the capability to dynamically adjust the radiation pattern according to a certain electromagnetic environment [1,2].

Basic reflector antenna that uses reflecting surfaces in certain configurations is known as corner-reflector antenna (CRA). The CRA was first introduced in 1940 by John D. Kraus [3]. Most of CRA use dipole as a feeder and two flat sheets intersecting at the corner apex angle, which is also known as included angle. The first work on corner reflector antennas, published by Kraus, applies image theory to a dipole parallel to the apex of a corner reflector [3]. Other authors have investigated this type of corner reflector antenna quite thoroughly. For example Wilson and Cottony have done extended work in measuring the field patterns of a finite size corner reflector antenna[4]. Wilson has investigated the CRA impedance as a function of the driven element geometrical parameters, assuming constant corner reflector dimensions [5]. Most theoretical investigations on reflector antennas are based on the concept of images. Javid and Brown have given a discussion of this concept in connection with Green's function [6]. Kraus discusses it strictly from the view of satisfying boundary conditions [7]. Kraus has also given a thorough discussion on methods of determining elliptical polarization. The earliest work on a corner reflector antenna in which the dipole element was tilted with respect to the apex of the corner was done by Woodward and Klopfenstein [7,8]. Basic guide to design CRA is well documented in many antenna reference books such as [10-13]. Recently, reactively controlled CRA was designed in for maximum directivity and multiple beam forming [14]. A mechanical approach was proposed in to achieve variable beam width CRA[15]. A reconfigurable plasma CRA was implemented in] at 2.4 GHz [16]. The CRA was designed for gain optimization using antenna Magus in [17].

Previous work on CRA was restricted to certain CRA parameters such as half-wave length dipole, or 90o apex angle, and the others investigated the CRA optimization with respect to specific antenna parameters such as gain only or beam width or impedance only. Therefore a comprehensive CRA performance analysis is proposed in this paper, where all CRA geometrical parameters are varied and observing the resultant pattern, directivity and the voltage standing wave ratio (VSWR) for each case. The resultant optimum parameters are then used to design and construct the DCRA for base station of GSM-900 cellular network. A novel mechanical approach is also proposed to tailor the required adaptive pattern and steer it to the heavy traffic sector in the 360o coverage area. The simulated and measured VSWR of the constructed DCRA are investigated and compared.

II. ANTENNA DESIGN CONCEPTS AND STRUCTURE

The proposed DCRA is comprised of a balanced dipole in front of a corner reflector made up of two joined plane conducting sheets, as shown in figure 1. The DCRA has the following geometrical parameters: dipole length; Ld, dipole spacing; S, corner length; L, corner height; H, corner apex angle; α and the corner reflector aperture; Dc. The DCRA is designed to be used as a base station antenna for GSM-900 (P, E, R, T) which extends from 870 MHz up to 960 MHz. The

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center frequency is fc = 915 MHz with corresponding center wavelength λc = 328 mm and bandwidth = ±45 MHz.

The analysis of the DCRA radiated field is facilitated by the use of image theory. The number of images, polarity, and position of each is controlled by the apex angle and the dipole polarization [9]. Image theory is also used to develop the far field and polarization equations. These equations are functions of all DCRA geometrical parameters (Ld, S, L, H, α) and the dipole tilt angle with the corner apex.

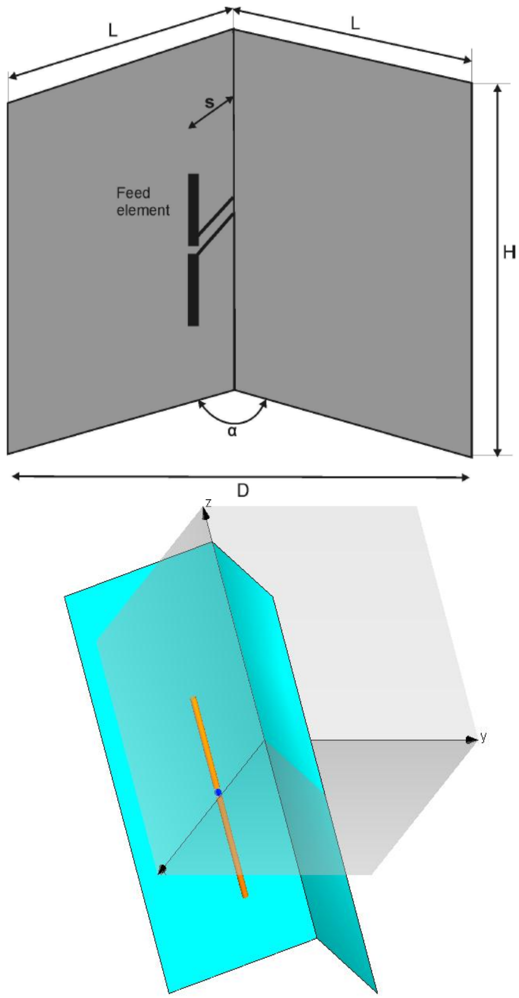


Fig. 1. DCRA geometrical parameters with WIPL-D simulation structure

Based on the theoretical analysis, standard parameters of the DCRA are first used to investigate the antenna performance for GSM-900, as illustrated by Table 1.

The listed parameters in the above table are plugged in WIPL-D software package, and the resultant VSWR within the whole bandwidth of GSM-900 is found practically acceptable as shown in Figure 2, where 1 < VSWR < 2.22.

Next the variation of the DCRA input impedance with the corner apex (included) angle; α, is investigated and compared with the results of A. C. Wilson [4], where the DCRA geometrical parameters are given as :

Corner length = L = λc = 328 mm at fc = 915 MHz
Corner height = H = 1.3 λc = 426.4 mm
Dipole length = Ld = λc /2 = 164 mm
Dipole spacing = S = 0.205 λc = 67.24 mm

Table I
Classical (standard) DCRA parameters.

The DCRA Parameter equation	Parameter value for GSM-900
The apex angle; α = 90o	α = 90o
The dipole length; $L_d = \lambda_c/2$	L_d = 164 mm
The feed to vertex distance; S: λc/3<S<2 λc/3	S = 163.5 mm
The corner length; L = 2S	L = 327 mm
The corner height; H = (1.2 : 1.5) L_d	H =221.5 mm
The corner aperture; Dc: $\lambda c<Dc<2\lambda_c$, where D_c could be calculated as $D_c = \sqrt[2]{(H_c \sin\alpha)^2 + (L_c - H_c\cos\alpha)^2}$	D_c = 395 mm,

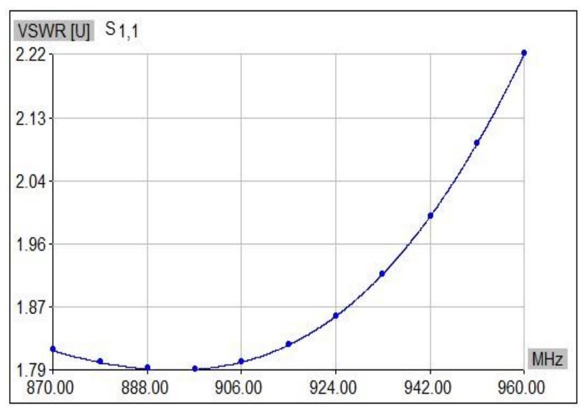


Fig. 2. VSWR over GSM-900 bandwidth of DCRA with parameters of Table I

The resultant VSWR over the whole GSM-900 bandwidth for the apex angle $\alpha = 90^o$ and $\alpha = 120^o$ are shown in Figures 3 and 4; respectively

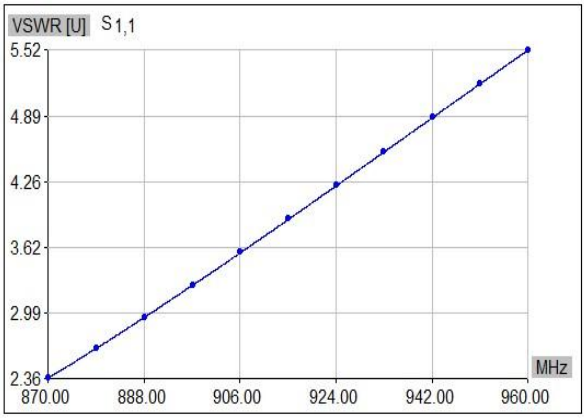


Fig. 3. VSWR of DCRA with the parameters listed above and α = 90^o

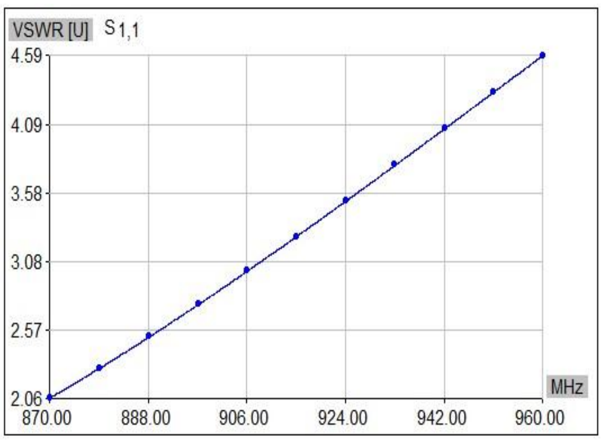


Fig. 4. VSWR of DCRA with the parameters listed above and α = 120^o

The simulated VSWR results are compared with those of [4] at the center frequency fc as in Table II.

Table II
the variation of the antenna input impedance versus apex angle α

The apex angle α	A. C. Wilson theoretical results	WIPL-D simulation results
α 1 = 90o	Z1 = 41+j96.5 Ω → VSWR1 = 6.41	VSWR1 = 4
α 2 = 120o	Z2 = 63+j114 Ω → VSWR2 = 6.02	VSWR2 = 3.25

It is noticed from table 2 that the VSWR is decreased as α increased from 90o to 120o as published in [4] or by WIPL-D simulation. The differences in VSWR values are probably due to the infinitely thin dipole assumed by theoretical calculations.

Varying the DCRA geometrical parameters produce different antenna patterns with different parameters to adapt to the changing electromagnetic environment as will be illustrated by the following cases.

<u>Case 1:</u> Changing the dipole length Ld from 160 mm up to 220 mm and keeping the other parameters constant at H=300mm, L=150mm, S=100mm and α=50^o

The worst VSWR = 3.24 is obtained at the largest L_d=220mm, while the best VSWR = 1.47 is obtained at the smallest L_d=160mm with the radiation pattern cuts as shown in Figure 5. The directivity and VSWR variation versus dipole length are also investigated and the results are shown in Figure 6. It is clear from Figure 6 that for the given antenna dimensions of case1, as the dipole length L_d increases the directivity D increases and the VSWR is getting worse. L_d should be less than 95 mm in order to have VSWR < 2. On the other hand, for D > 7 dB, L_d should be larger than 95 mm.

<u>Case 2:</u> Changing the apex angle from 15o up to 120o and keeping the other parameters constant at L_d = 200mm, H=300mm, L = 150mm, and S = 100mm.

The worst VSWR = 2.52 is obtained at α = 50o, while the best VSWR = 1.01 is obtained at α = 75o with the pattern cuts as shown in Figure 7.

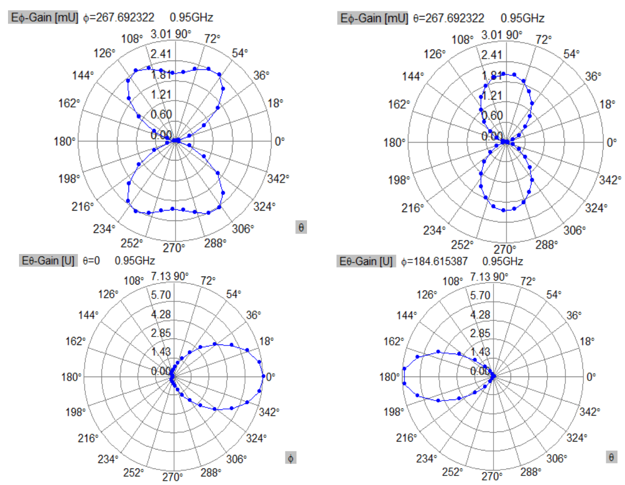


Fig. 5. The DCRA patterns with the lowest VSWR=1.47 are obtained at L_d=160mm and directivity D= 7dB

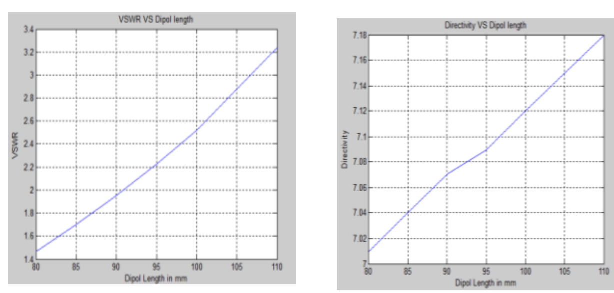


Figure.6. VSWR and Directivity variation vs. Dipole length

The patterns of Figure 7 have attractive features, where 4 major lobes are formed at 45o, 135o, 225o and 315o, while beam nulls occur within different 4 sectors centred at 0o, 90o, 180o and 270o. The directivity and VSWR variation versus the corner angle are also investigated and the results are shown in Figure 8, where VSWR is oscillating between 1.and 2.5 as the corner angle α changes, while the directivity D is almost constant and slightly above 7 dB for α less than 75o. For larger α, D is badly deteriorated down to 3.5 dB.

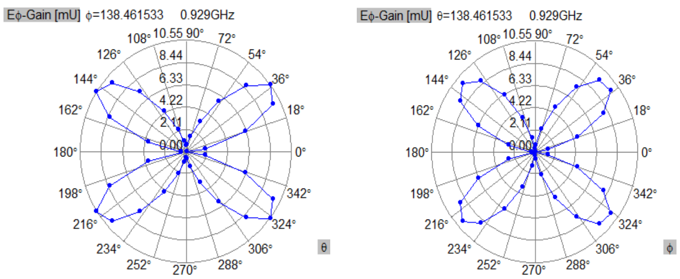


Fig. 7. DCRA patterns with the lowest VSWR=1.01 are obtained at α=75o and directivity D= 7.15dB.

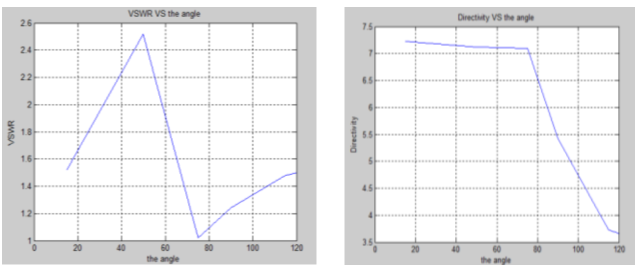
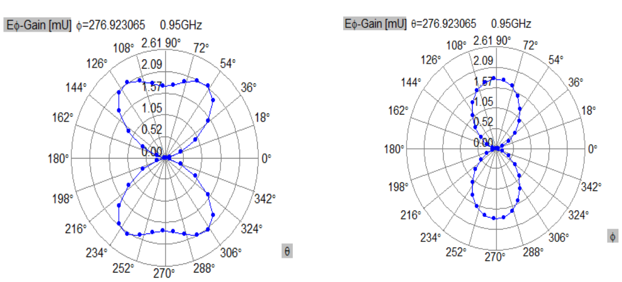


Fig. 8. VSWR and Directivity variation vs. the corner angle

<u>Case 3:</u> Changing the spacing S from 70 up to 120mm and keeping the other parameters constant at L_d=200mm, H=300mm, L=150mm, and α=50^o.

The worst VSWR = 6.8 is obtained at S = 70mm, while the best VSWR = 1.57 is obtained at S = 70mm with the pattern cuts as shown in figure 9. The directivity and VSWR variation versus the dipole spacing S are also investigated and the results are shown in Figure 10. It is clear from Figure 10 that VSWR decreases as S increases. The dipole spacing S should be larger than 110 mm (λc / 3) to yield VSWR less than 2. While, 75 mm < S < 110 mm is a condition to have the directivity D larger than 7 dB.



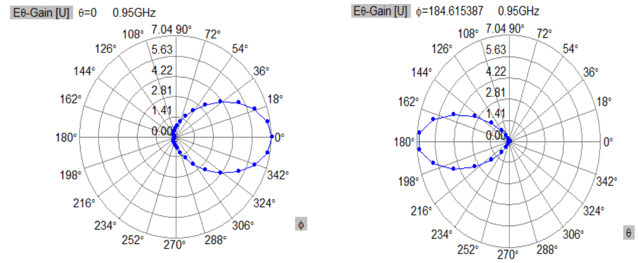


Fig. 9. DCRA patterns with the lowest VSWR=1.57 obtained at S = 120mm and directivity D= 6.92dB

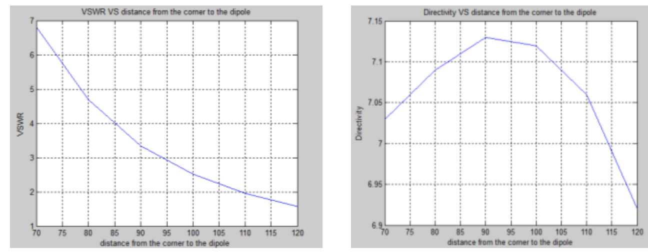


Fig. 10. VSWR and Directivity variation vs. the dipole spacing S

<u>Case 4:</u> Changing the reflector length L from 120 up to 170mm and keeping the other parameters constant at L_d=200mm, H=300mm, S=100mm and α=50^o.

The worst VSWR = 2.6 is obtained at the largest L = 170mm, while the best VSWR = 2.1 is obtained at the smallest L = 120mm with the pattern cuts as shown in Figure 11.The directivity and VSWR variation versus the corner length L are also investigated and the results are shown in Figure 12, where both D and VSWR increase as the corner reflector plate length L increases .

<u>Case 5:</u> Changing the reflector height H from 150 up to 400mm and keeping the other parameters constant at Ld=200mm, L=150mm, S=100mm and α=50^o.

The worst VSWR = 3.8 is obtained at H = 200mm, while the best VSWR = 1.9 is obtained at the smallest H = 150mm with the pattern cuts as shown in Figure 13. It is noticed from Figure 13 that the back lobe starts to appear in the Eθ pattern at ϕ = 0 plane, because the chosen dipole length Ld = 200 mm is larger than the reflector plate height H = 150 mm. CRA with reflector plate heights shorter than the feed dipole length loses its unidirectional property. The directivity and VSWR variation versus the corner height H are also investigated and the results are shown in Figure 14, where the corner reflector plate height H should be larger than 300 mm to get practically acceptable VSWR ≈ 2 and directivity more than 7 dB.

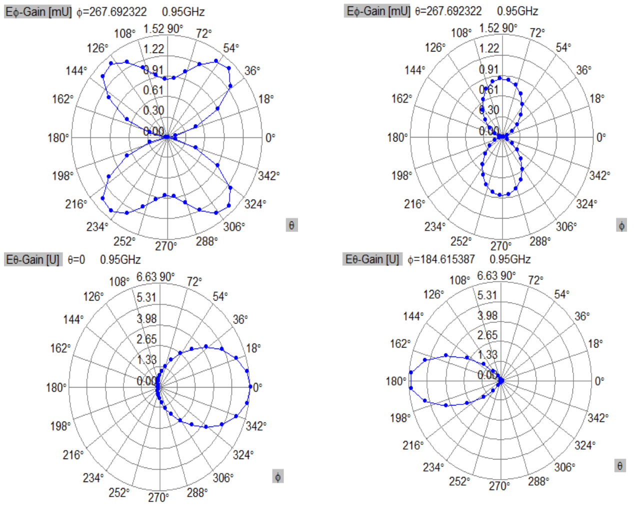


Fig. 11. DCRA patterns with the lowest VSWR=2.1 are obtained at L = 120mm and directivity D= 6.54dB

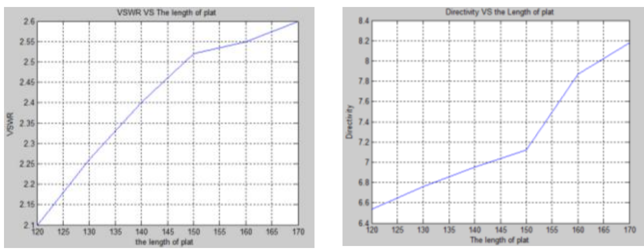


Fig. 12. VSWR and Directivity variation vs. the corner length L

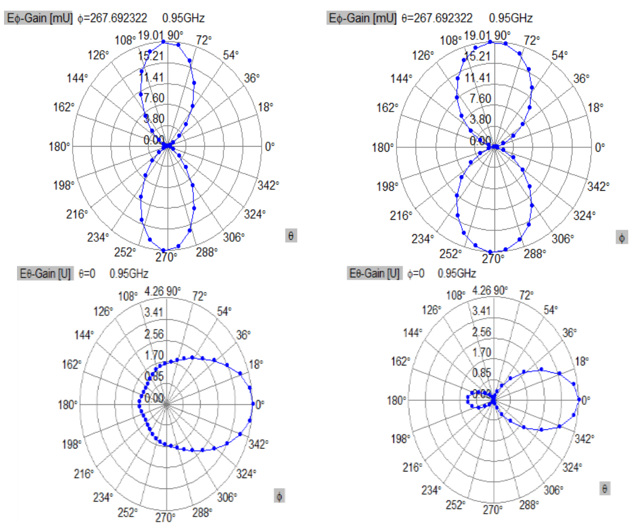


Fig. 13. DCRA patterns with the lowest VSWR=1.9 are obtained at Hc = 150mm, but with lowest directivity D= 4.04dB.

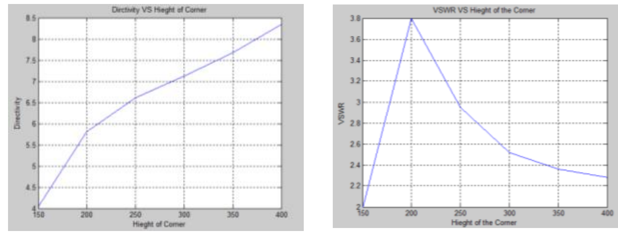


Fig. 14. VSWR and Directivity variation vs. Corner height H

II. Measurements and Results

From the results of the extensive DCRA simulation in section II, the optimum dimensions have been chosen to realize the first prototype to be used as a base station antenna for GSM-900 cellular network. A sample of the DCRA dimensions is proposed for the hardware construction as H = 480 mm, L = 500 mm, Ld= 150 mm, α=90o and dipole spacing = S = 170 mm. The resultant VSWR variation of the constructed DCRA versus the frequency band of GSM-900 is shown in Figure 15; where VSWR is lower than 2.16 all over the whole bandwidth of GSM-900.

The DCRA is then constructed as shown in Figure 16, where two hinged copper sheets are used to form the corner reflector and the split-type balun, shown in Figure 17 is used to feed the balanced dipole, which is made of two telescopic arms.

The antenna pattern and parameters of the constructed DCRA are made adaptive by controlling its geometrical parameters via mechanical approach, where a motor is used to change the corner angle α from 0o up to 180o. The second motor is used to slide the balun assembly forward and backward to change the dipole spacing S, while the third motor is used to rotate the balun tube changing the dipole tilt angle producing different polarizations. The fourth motor is used to rotate the whole DCRA structure 3600 to realize the switching property.

The VSWR is measured for the constructed DCRA at different apex angles, dipole length, spacing and orientation. The device used for VSWR measurements is Bird Site Hawk Analyzer SK-4000-TC (85-4000 MHz). Generally, most of the measured VSWR are found below 2 over the GSM-900 frequency band, as is shown in the measurement sample of Figure 18. The measured VSWR sample is compared with the simulation results of Figure 15 as shown in Figure 19. The discrepancy is probably due to calibration errors, dimensions tolerance and fabrication defects of the first constructed DCRA prototype, which is under improvement.

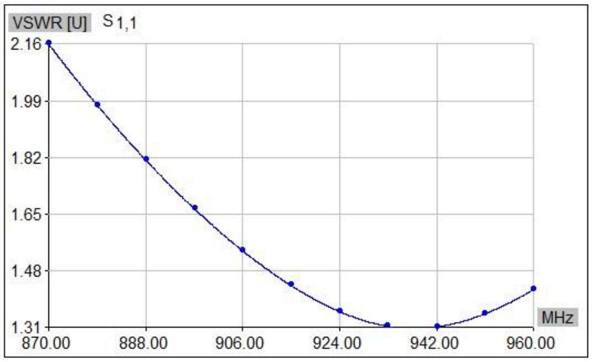


Fig. 15. Simulated VSWR of the constructed DCRA

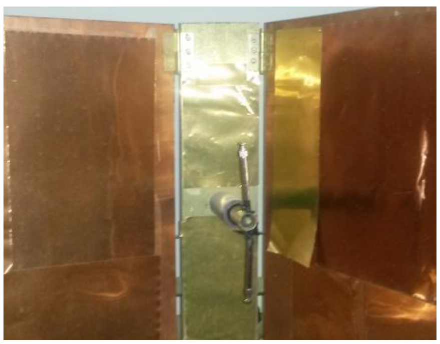


Fig. 16. Constructed DCRA

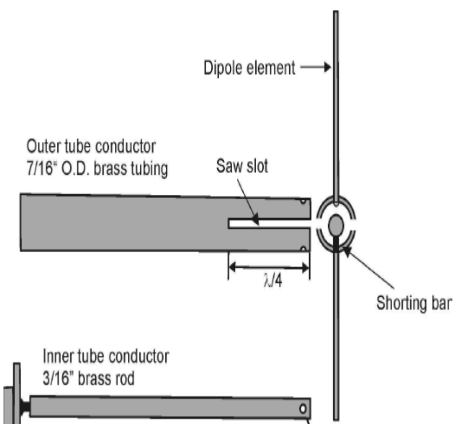


Fig. 17 Dipole and split balun assembly

Fig. 18. VSWR Measurement setup

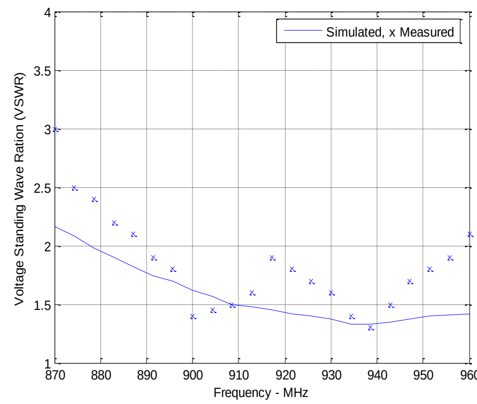


Fig. 19. Simulated and Measured VSWR

III. Conclusions

Corner reflector antenna has been designed and simulated with different parameters to produce different antenna patterns. The radiation characteristics such as the radiation patterns in different planes, directivity and voltage standing wave ratio have been observed and discussed for each case as in section II. The optimum DCRA geometrical parameters that provide maximum directivity and lowest VSWR are clarified. The comprehensive DCRA simulation results performed by WIPL-D and presented in this paper provides a data base of predefined DCRA geometrical parameters with their corresponding antenna patterns to deal with different electromagnetic scenarios. Moreover, the comprehensive performance analysis, which includes the best and worst case studies of directivity and VSWR, reveals important aspects of DCRA that have not been investigated before and leads to further improvements in DCRA design. The DCRA has been designed, simulated and implemented for base station of GSM-900 cellular network. The VSWR of the constructed DCRA has been measured and found to be below 2 over most of the GSM-900 frequency band. A mechanical approach has been proposed to achieve both antenna pattern shaping and radiation sector steering with different polarizations. The

DCRA geometrical parameters such as dipole length, diameter, orientation and spacing in addition to the corner angle are controlled via several motors. Moreover, the whole antenna structure could be rotated 360o to direct the antenna pattern to certain heavy traffic sectors at any time. The implemented simple and low cost DCRA permits both beam switching and shaping without sophisticated digital signal processing techniques. Moreover, such antenna system could be easily integrated with the base station of the already installed cellular networks to improve its performance.

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