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A DUAL-BAND DUAL-POLARIZED MICROSTRIP ARRAY ANTENNA FOR BASE STATIONS

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Abstract—This paper presents a new dual-band, dual-polarized 1×4 antenna array design for telecommunication base station. One of the bands covers global system for mobile communication (GSM) band, while the other covers both digital communication system (DCS) and universal mobile telecommunication system (UMTS) bands. The antenna is based upon an aperture stacked patch layout and incorporates a simple and novel dual-layered feeding technique to achieve dual polarized radiation. For feeding the array elements, a corporate feed network is used. In order to achieve appropriate matching in both bands, a three-section Chebyshev transformer has been designed. The proposed antenna shows good port decoupling, less than -30 dB for dual linear polarization over its operating bands. Peak antenna gains about 11 dBi and 11.6 dBi have been obtained for lower and upper bands, respectively. The effort was directed toward the design of a single standalone dual-polarized antenna to cover all three bands.

1. INTRODUCTION

Development of essentially new base station antennas has become one of the most important tasks in contemporary antenna engineering. Along with rapid wireless communication development, the number of base station antennas has also been increased. In coming years, the new generation of wireless communication systems will demand new and improved base station antennas. These new base station antennas

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will need to operate in both 2G and 3G frequency bands, being either dual-band or multi-band, and would replace current sectored antennas by a single antenna to reduce the overall number of antennas on cellular base stations. In Europe, this means that there is a demand for antenna elements capable of handling GSM (880–960 MHz), DCS (1710–1880 MHz), and UMTS (1920–2170 MHz) bands [1].

In the past two decades, many techniques for the design of patch antenna with multiple-frequency operation have been investigated and proposed [2–7]. On the other hand, polarization diversity technique is popular due to increase of the system capacity. This promotes research on dual-polarized patch antennas, which can transmit and receive two orthogonally polarized signals simultaneously with a single antenna system. Patch antennas with dual-polarized operation capabilities are very appropriate for applications in modern mobile communication systems to combat the multipath fading problem, which usually causes layer degradation in the system performance [8]. For such applications, a variety of dual-polarized patch antennas with single band operation have been reported [8–13].

The most popular technique to obtain a dual-frequency behavior is introducing a reactive loading to a single patch [14]. By loading an inset or a notch on the radiating patch, a dual-frequency behavior as well as size reduction is obtained [15]. In [15] a dual and wide band aperture stacked patch antenna with double-sided notches has been presented.

Very few designs with dual-band dual-polarized operations have been reported for application in mobile communication systems. The proposed antenna in [1] demonstrates a triple band dual polarized antenna whose first band covered GSM and the second band covered both DCS & UMTS. For each of these bands, the antenna provides 2 orthogonal linear polarizations with a good isolation between the ports. The reported design in [8] presents a compact dual-band dual-polarized patch antenna suitable for the 900 and 1800 MHz band operations. The proposed antenna comprises of two coplanar radiating patches, one rectangular-ring patch for 900 MHz operations, and the other slated rectangular patch implemented within the rectangular ring patch for 1800 MHz operations. To feed this antenna, using the aperture-coupled excitation method, four H-shaped coupling slots were cut in the antenna's ground plane.

To achieve higher gain and shaped pattern, antenna array is much popular in industry, especially for base station applications. Significant progress has been made in the design of multiband antennas with good bandwidth performance in two or even three different bands. For most part, researches have been concerned with the design of isolated multiband array design. In [16] a $\pm 45^\circ$ slant dual-polarized, 1×8 dual-band antenna array suitable for base station antenna in GSM900 and DCS1800 MHz bands with isolation more than 30 dB between ports has been proposed. The array comprises two 4-element sub-arrays, one for GSM900 and other for DCS1800. A corporate feed network has been used to feed both sub-arrays. Moreover, separator filters before each element have been employed to separate two frequency bands. In [17], a dual-band dual-polarized patch antenna array has been proposed. The antenna in [17] operates in two separate frequency bands, including 820–960 MHz and 1710–2170 MHz, which cover the operating frequencies of most mobile communication systems including CDMA, GSM, PCS, and UMTS has been proposed. The array consists of six elements with two larger patches for the lower band and four smaller patches for the upper band. Each patch element is excited from the side by two orthogonal L-shaped probes, for $\pm 45^\circ$ polarizations. A novel combination technique to achieve the optimization of both the element geometry and array layout of multiband BTS array antennas has been introduced in [18].

In this paper, a 1×4 dual-band dual-polarized patch antenna array suitable for use in base stations with polarization diversity is presented. Each radiating element is a double-sided notch patch that resonates in two bands. The first band can cover GSM, and the other covers both DCS and UMTS. In other words, it is, in fact, a triple band patch antenna. For feeding the array elements, a corporate feed network with a three-section dual-band Chebyshev transformer is designed. With this dual-band transformer, we have appropriate matching in both bands.

Two microstrip excitation networks are placed on separate substrates on the opposite sides of the ground plane. The polarization isolation is greater than 30 dB in both bands. The total size of the array is about 660 mm $\times$ 300 mm $\times$ 21.8 mm and the gains about 11 dBi and 11.6 dBi for lower and upper bands, respectively. In comparison with similar works in this area, the proposed antenna array offers relatively small dimensions, simple structure, and smaller number of layers. Employing FR4 substrate makes it also a low cost structure. Other advantages of the proposed antenna is using only one port for each polarization feed at all three frequency bands and utilizing a total of only two feeding port. It must also be noted that this array is designed with triple band patches instead of separate patches for each band.

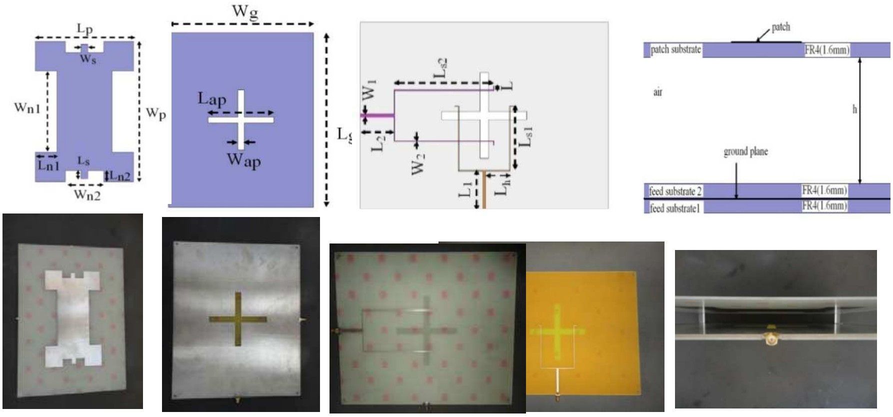


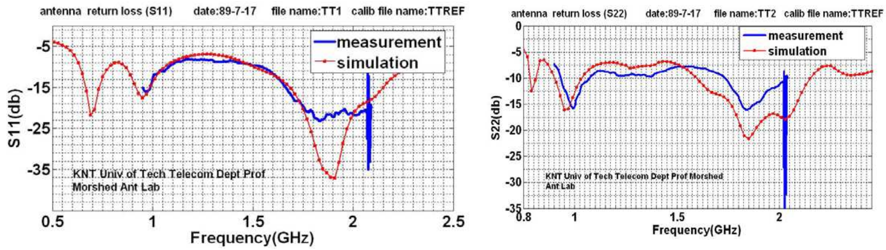
Figure 1. Geometry of the proposed antenna element. (a) Patch in layer 1. (b) Coupling slots in ground plane. (c) Microstrip-line feed network. (d) Side view of the antenna.

2. SINGLE ELEMENT ANTENNA CONFIGURATION

The configuration of a single element of the array and the fabricated single element antenna are shown in Figure 1. As can be seen from Figure 1, one rectangular patch with double sided notches is mounted on multiple dielectric layers. To reduce the cost of antenna fabrication and making it more rigid in construction, FR4 substrates are used. The antenna consists of 4 layers, 3 layers of FR4 dielectric material ($\varepsilon_r = 4.4$) and 1 air layer ($\varepsilon_r = 1$). Foam material is added between the patch and ground plane, thereby increasing its total height and reducing its effective dielectric constant. To achieve a dual polarized operation, two microstrip feed layers are placed on separate FR4 substrates at the opposite sides of the ground plane.

3. SIMULATION AND MEASURED RESULTS OF SINGLE ELEMENT

To verify the proposed design, a prototype of the single element antenna with optimized dimensions has been fabricated. The measurement and HFSS simulation results are shown in Figures 2 to 4. The HFSS simulation results in Figure 2 show the impedance bandwidth (VSWR < 2) of 145 MHz or 14.6% at GSM and 620 MHz or 32.6% at DCS and UMTS for port 1 and 125 MHz or 14.1% at



(a) (b)

Figure 2. Return loss as a function of frequency. (a) Port 1. (b) Port 2. $L_D = 115\,\text{mm}$, $W_D = 190\,\text{mm}$, $L_{n1} = 20\,\text{mm}$, $W_{n1} = 110\,\text{mm}$, $L_{n2} = 15\,\text{mm}$, $W_{n2} = 45\,\text{mm}$, $L_s = 10\,\text{mm}$, $W_s = 8\,\text{mm}$, $L_g = 290\,\text{mm}$,$W_g = 220\,\text{mm}$, $L_{ap} = 100\,\text{mm}$, $W_{ap} = 10\,\text{mm}$, $L_1 = 45\,\text{mm}$, $L_2 = 40\,\text{mm}$, $W_1 = 3.06\,\text{mm}$, $W_2 = 0.7\,\text{mm}$, $L_{S1} = 75\,\text{mm}$, $L_{S2} = 115\,\text{mm}$, $L_h = 30.24\,\text{mm}$, $L = 5\,\text{mm}$, $h = 17\,\text{mm}$.

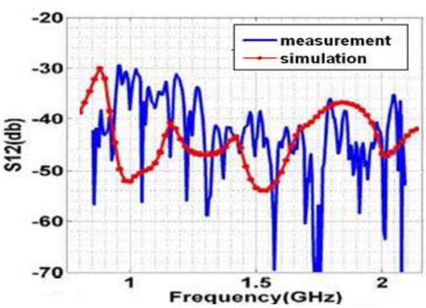


Figure 3. Isolation between ports as a function of frequency.

GSM900 and 480 MHz or 24.7% at DCS1800 and UMTS for port 2. It is clearly observed that dual and wide operating bandwidths are obtained. The input impedance for the two ports will differ slightly if there exists a coupling from the upper feed network to the patch element. However, direct coupling from the feed line to the patch would be minimal because of thick layers used between the slot and the patch. The port decoupling is less than 30 dB in both bands as presented in Figure 3.

The simulated radiation patterns in two principle planes at 900, 1800, and 2100 MHz are plotted in Figure 4. HPBWs at $\varphi = 0°$ plane are 63°, 85° and 64°, while those at $\varphi = 90°$ plane are 56°, 44° and 32° for GSM, DCS and UMTS, respectively. Note that if the antenna is used as an array element, the vertical radiation pattern of individual elements would not be critical, provided that it is relatively broad, as the array's vertical pattern will be determined by the vertical stacking of multiple elements. Figure 5 shows the antenna gains as a function of frequency. For the GSM (880 MHz–960 MHz) band, a peak antenna gain of 11.8 dBi is observed. For upper frequency band, the peak gain is 7 dBi. The gain of the dual-polarized aperture stacked patch antenna drops off at higher frequencies, beyond 2 GHz, due to the dominant

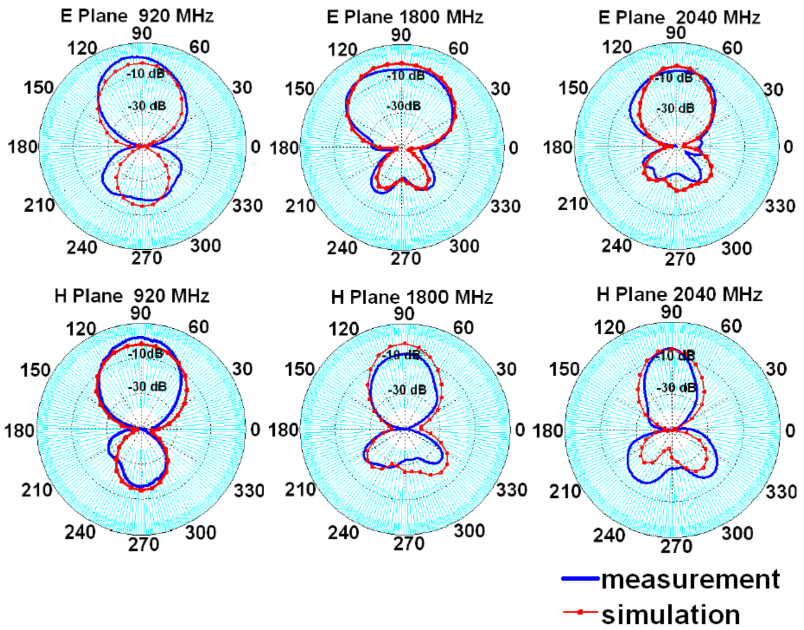
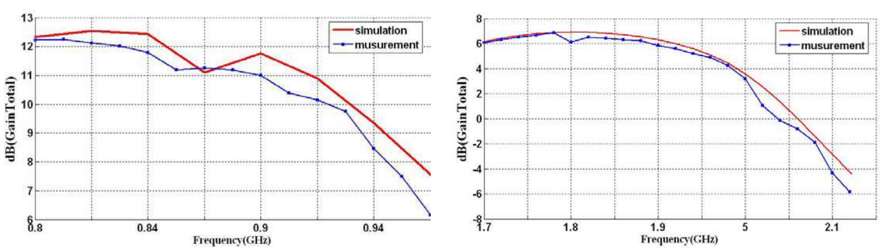


Figure 4. Radiation patterns of single element antenna at 920 MHz, 1800 MHz, and 2040 MHz.



(a) (b)

Figure 5. Antenna gain as a function of frequency. (a) GSM900 band. (b) DCS1800 band.

radiation mechanism of the slot. Moreover, the other reason can be due to using of FR4. The losses for high frequencies in a microstrip structure are too high, and dielectric constant of this material is very instable at high frequencies. To resolve this problem, improve the shape of the pattern and make them narrower and suitable as a base station antenna, the proposed antenna must be placed in an array combination. The results are summarized in Table 1. The discrepancy between the simulated and measured results can be mostly attributed to the measured environment effect and the tolerance in manufacturing.

4. ARRAY DESIGN

The gain of a base station antenna is typically many times larger than the gain provided by a single radiating element. Therefore, it is necessary to employ a number of elements in an array combination to achieve the required gain and pattern characteristics.

Having chosen the types of triple-band, dual-polarized radiating elements and feed lines to be used, our next task is the design of array structure. In order to minimize the cost, we wish to use the minimum necessary number of elements.

First, a two element array is designed and simulated. There are some considerations in array design that must be taken into consideration. The most important one is the element spacing. In general, the array elements should be as far as possible from each other, so the mutual coupling becomes negligible. On the other hand, in order to avoid grating lobes in the radiation patterns, the elements spacing must be less than $0.7\lambda_0$. If a single patch multi-

Table 1. Summary of single element simulation results.

		GSM	DCS	UMTS
BW	Port 1	14.6%	32.6%	
	Port 2	14.1%	24.7%	
HPBW	Horizontal $\varphi = 0$	63°	85°	64°
	Vertical $\varphi = 90$	56°	44°	32°
Gain		11.8 dBi	7 dBi	
Isolation between ports		≤ -45 dB	≤ -43 dB	≤ -35 dB
polarization		0 & 90°	0 & 90°	0 & 90°
F/B		21.2	23.1 dB	4.1 dB
VSWR		≤ 2	≤ 2	≤ 2
Dimension		22 cm × 29 cm × 21.4 cm		

band design is chosen as the composite element for the array, it will be very difficult to ensure that this condition is satisfied across all operating bands. Therefore, an optimized distance for each band must be selected in the range of $0.5\lambda_0$ to $0.7\lambda_0$. However, the main problem is that an optimized distance for lower band may not be suitable for upper band and vice versa. In order to find an optimized distance for which the array performance is acceptable in both lower and upper bands, the distance "d" between array elements was varied from $0.4\lambda_{900} = 0.8\lambda_{1800} = 140\,\text{mm}$ to $0.7\lambda_{900} = 1.4\lambda_{1800} = 230\,\text{mm}$, until the optimized value of $d = 0.48\lambda_{900} = 0.96\lambda_{1800} = 160\,\text{mm}$ is obtained.

The proposed structure has two feeding ports in two layers. Therefore, two separate excitation networks are designed and placed on a layer where the corresponding feeding port is located. Each one of the excitation networks must have an appropriate matching in both low and high bands simultaneously, and feed the array in a specific direction. For feeding each element of the array, a corporate feed network is used for each port. For a 1×2 array, there are two patches with $50\,\Omega$ input impedances. On the other hand, each excitation port must feed both patches. Each port is a $50\,\Omega$ line and divided into two $100\,\Omega$ branches. Therefore, each of the $100\,\Omega$ branches must be matched to a patch with $50\,\Omega$ input impedance.

Table 2. Parameter values for the microstrip-line sections in the two-section dual-band impedance transformer.

Line No.	Characteristic impedance	width	length
1	$63.73\,\Omega$	1.68 mm	29 mm
2	$78.45\,\Omega$	1.1 mm	29 mm

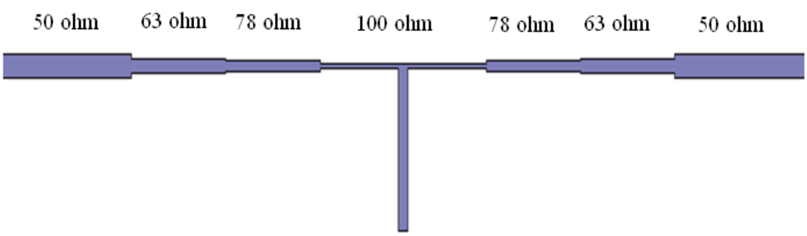


Figure 6. Three section Chebysheve transformer for impedance matching.

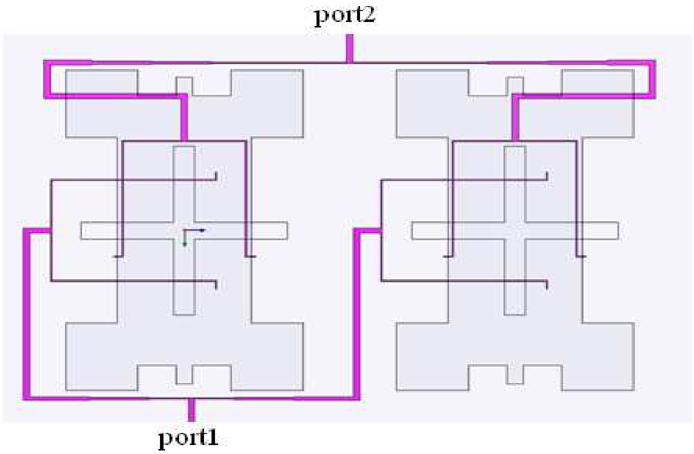


Figure 7. Element positions and feed network of 1×2 tri-band array.

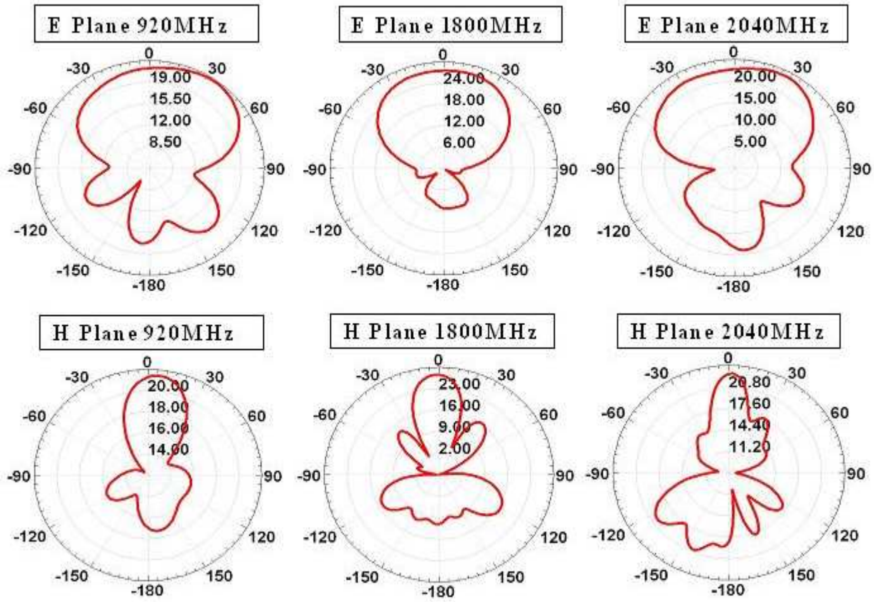


Figure 8. Radiation patterns in E and H plane of the antenna at 920 MHz, 1800 MHz, and 2040 MHz.

In order to achieve an appropriate matching in both bands, a two-section dual-band Chebyshev impedance transformer, which has matching capability at two arbitrary frequencies, was designed [19, 20]. Design parameters for this transformer, which consist of characteristic impedance and lengths of each section, were determined at central frequencies of 920 MHz and 1940 MHz to match a 100 Ω line to a 50 Ω line. After determining impedances, the widths of the microstrip-line sections of the feed network were calculated for $\varepsilon_r = 4.4$ and $h = 1.6$ mm and summarized in Table 2. This matching transformer and the configuration of 1×2 antenna array are shown in Figures 6 and 7, respectively.

This two element array is simulated by HFSS, and its radiation patterns in two principle planes at frequencies of 900, 1800 and 2100 MHz are shown in Figure 8. It can be seen that the HPBW

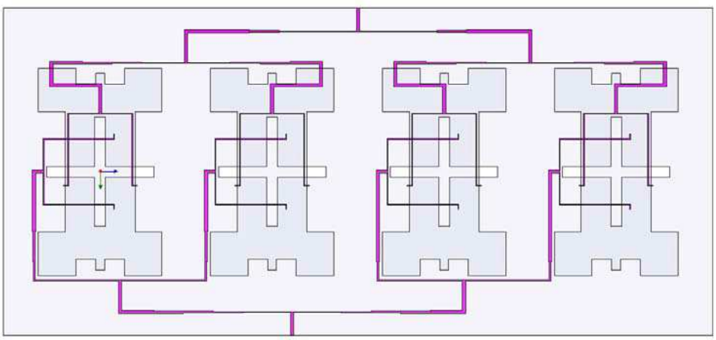


Figure 9. The configuration of 1×4 antenna array.

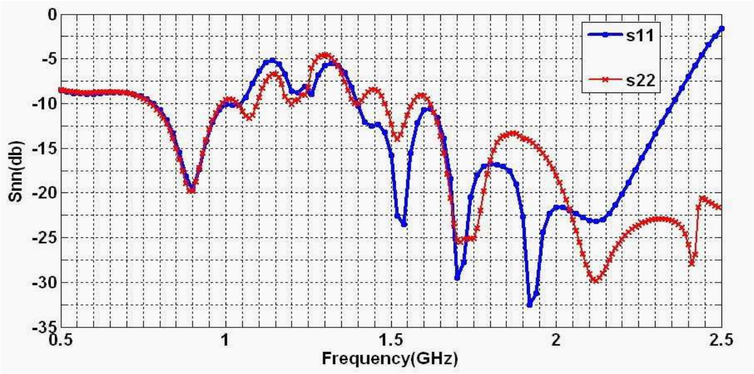


Figure 10. Simulated return loss versus frequency, port 1 and port 2.

at $\varphi = 0$ plane is equal to 104.7°, 84.2° and 116.4°, and at $\varphi = 90$ plane equal to 50°, 22° and 22.8° for GSM, DCS and UMTS bands, respectively. It is obvious that in comparison with the case of single element, the vertical patterns are narrower and much closer to the pattern criteria of BTS antennas. However, these patterns were still improper for intended application. In order to have more suitable patterns and narrower vertical beam width, a 1×4 array was designed. For back radiation reduction from the aperture, a ground plane is placed under the antenna with 28.4 mm distance from the slot. The configuration of 1×4 antenna array is shown in Figure 9.

5. RESULT AND DISCUSSION

The HFSS simulation results in Figure 10 show that the impedance bandwidth (VSWR < 1.5) for port 1 at GSM900, DCS1800, and UMTS bands is equal to 90 MHz (10%), 220 MHz (12.2%), and 490 MHz (22.4%), respectively. While for port 2, it has the values of 100 MHz (11.9%) at GSM, 460 MHz (26.8%) at DCS and 740 MHz (31%) at UMTS. It is clearly observed that dual-band operation with wide bandwidths is obtained. The input impedance for two ports may be slightly different, because of the possible coupling of upper feed network to the patch element. But in general, the direct coupling from the feed lines to the patch is minimized because thick dielectric layers are used between the ground plane slot and the patch. As represented in Figure 11, we have achieved the port decoupling of less than -30 dB in all bands.

The simulated radiation patterns in two principle planes at the

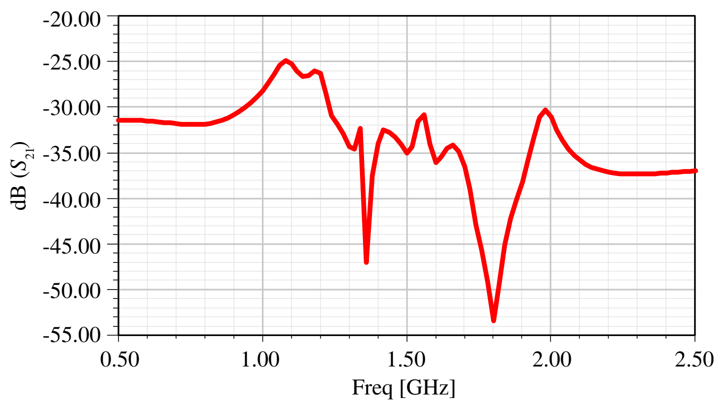


Figure 11. Isolation between ports versus frequency.

frequencies of 900, 1800 and 2100 MHz are plotted in Figure 12. It can be seen that the HPBW at $\varphi = 0$ plane is equal to 57°, 77° and 70°, and at $\varphi = 90$ plane equal to 26°, 11° and 12° for GSM, DCS and UMTS bands, respectively.

Figure 13 depicts the simulated antenna gain as a function of

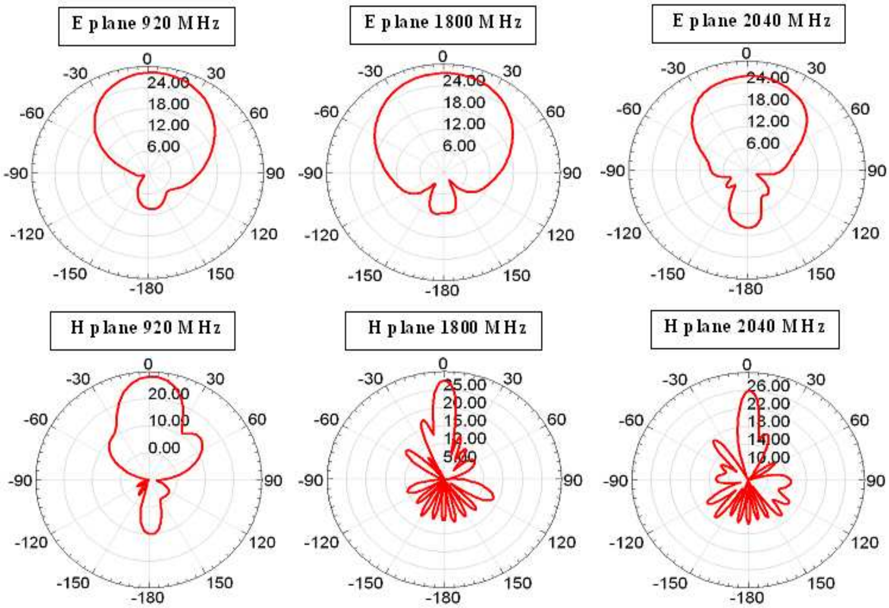


Figure 12. Simulated radiation patterns in E and H planes of the antenna at 920 MHz, 1800 MHz, and 2040 MHz.

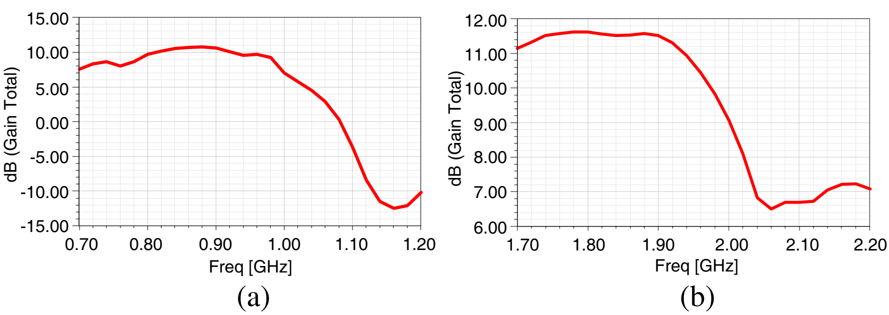


Figure 13. Simulated antenna gain versus frequency. (a) Lower band. (b) Upper band.

Table 3. Summary of the 1×4 array simulation results.

		GSM	DCS	UMTS
BW	Port 1	10%	12.2%	22.4%
	Port 2	11.9%	26.8%	31%
HPBW	Horizontal $\varphi = 0$	57°	77°	70°
	Vertical $\varphi = 90$	26°	11°	12°
Gain		11 dBi	11.6 dBi	
Isolation between ports		≤ -35 dB	≤ -40 dB	≤ -30 dB
polarization		0 & 90°	0 & 90°	0 & 90°
F/B		13.3 dB	11 dB	10.28 dB
VSWR		≤ 1.5	≤ 1.5	≤ 1.5
Dimension		66 cm × 30 cm × 21.4 cm		

frequency. For the lower band, a peak antenna gain of 11 dBi is observed. For upper frequency band, the peak gain is 11.6 dBi. As can be seen in comparison with single element and two elements array, the vertical patterns are narrower, back lobes reduced, and gain problem in higher bands solved. Therefore, with this beam width and gain, the array is more suitable for base stations. The results are summarized in Table 3.

In comparison with [18], our design has better return loss performance and offers very few grating lobes in the vertical radiation pattern. [17] also presents an array which covers mentioned bands. The gain of the proposed array in [17] is about 10.5 dBi in the lower band and around 14 dBi in upper band. Although the gain in upper band is more than the gain of our design (11.6 dBi), in the lower band that is less than our design. Length and height of the proposed array in this paper is smaller and radiation patterns more suitable. Also for the proposed antenna in [17], separate patches for each band have been designed while our design has only single patch for three bands. In [16] the gain of the array is about 12 dBi at each band, but the proposed array covers only GSM900 and DCS1800, not UMTS 2100.

6. CONCLUSION

A new dual-band dual-polarized array antenna, operating in GSM900 as its lower band and DCS1800 — UMTS2100 as its upper band, is proposed. This array antenna is composed of tri-band patches instead of separate patches for each band. The simulated characteristics of the proposed configuration satisfy the requirements for cellular communication systems. The key to the design is the use of two substrates, one on the top of the aperture and the other below. In this design, we could avoid designing three separate patches for each band and have only single patch. We could overcome the problems of placing this triple band patches with appropriate spacing for all bands in an array that has the suitable pattern with acceptable grating lobes. Dual-polarized operation has been achieved with a simple technique.

REFERENCES

1. Deillon, V., J.-F. Zürcher, and A. K. Skrivervik, "A compact dual-band dual-polarized antenna element for GSM/DCS/UMTS base stations," *Microwave and Optical Technology Lett.*, Vol. 40, No. 1, 29–33, Jan. 2004.
2. Montero-de-Paz, J., E. Ugarte-Munoz, F. J. Herraiz-Martnez, V. Gonzalez-Posadas, L. E. Garcia-Munoz, and D. Segovia-Vargas, "Multifrequency self-diplexed single patch antennas loaded with split ring resonators," *Progress In Electromagnetics Research*, Vol. 113, 47–66, 2011.
3. Liao, W.-J., S.-H. Chang, and L.-K. Li, "A compact planar multiband antenna for integrated mobile devices," *Progress In Electromagnetics Research*, Vol. 109, 1–16, 2010.
4. Behera, S. and K. J. Vinoy, "Microstrip square ring antenna for dual-band operation," *Progress In Electromagnetics Research*, Vol. 93, 41–56, 2009.
5. Alkanhal, M. A. S. and A. F. Sheta, "A novel dual-band reconfigurable square-ring microstrip antenna," *Progress In Electromagnetics Research*, Vol. 70, 337–349, 2007.
6. Sze, J.-Y., T.-H. Hu, and T.-J. Chen, "Compact dual-band annular-ring slot antenna with meandered grounded strip," *Progress In Electromagnetics Research*, Vol. 95, 299–308, 2009.
7. Foroozesh, A., M. N. M. Kehn, and L. Shafai, "Application of artificial ground planes in dual-band orthogonally-polarized low-profile high-gain planar antenna design," *Progress In Electromagnetics Research*, Vol. 84, 407–436, 2008.
8. Chiou, T. W. and K. L. Wong, "A compact dual-band dual-polarized patch antenna for 900/1800-MHz cellular systems," *IEEE Trans. Antennas Propagat.*, Vol. 51, No. 8, 1936–1940, Agu. 2003.
9. Peng, H.-L., W.-Y. Yin, J.-F. Mao, D. Huo, X. Hang, and L. Zhou, "A compact dual-polarized broadband antenna with

hybrid beam-forming capabilites," *Progress In Electromagnetics Research*, Vol. 118, 253–271, 2011.

10. Sanford, J. R. and A. Tengs, "A two substrate dual polarised aperture coupled patch," *Proc. IEEE Trans. Antennas and Propagation Symp. Digest*, 1544–1547, 1996.
11. Masa-Campos, J. L. and F. Gonzalez-Fernandez, "Dual linear/circular polarized plannar antenna with low profile double-layer polarizer of $\pm 45^\circ$ tilted metallic strips for WiMAX application," *Progress In Electromagnetics Research*, Vol. 98, 221–231, 2009.
12. Ghorbani, K. and R. B. Waterhouse, "Dual polarized wide band aperture stacked patch antennas," *IEEE Trans. Antennas Propagat.*, Vol. 52, No. 8, 2171–2174, Aug. 2004.
13. Secmen, M. and A. Hizal, "A dual-polarized wide-band patch antenna for indoor mobile communication applications," *Progress In Electromagnetics Research*, Vol. 100, 189–200, 2010.
14. Heidari, A. A., M. Heyrani, and M. Nakhkash, "A dual-band circularly polarized stub loaded microstrip patch antenna for GPS application," *Progress In Electromagnetics Research*, Vol. 92, 195–208, 2009.
15. Oh, K., B. Kim, and J. Choi, "Design of dual and wideband aperture stacked patch antenna with double-sided notches," *Electronic Lett.*, Vol. 40, No. 11, May 2004.
16. Amiri, N., K. Forooraghi, and R. Dehbashi, "A compact dual-polarized aperture-coupled stacked patch antenna for GSM900 MHz," *IEEE 2005 Asia-Pacific Symposium on EMC, APEMC2005*, Taiwan, Dec. 2006.
17. Li, P. and K. M. Luk, "Novel wideband dual-frequency patch antenna array for dual-polarization operation," *Proceedings of the 2005 Asia-Pacific Microwave Conference*, Suzhou, Dec. 2005.
18. Starke, P. L. and G. G. Cook, "Optimized design of multi-band cellular base station antenna array for GSM and UMTS deployment," *IET Microwave, Antennas and Propagation*, Vol. 3, No. 2, 333–347, 2009.
19. Yang, R.-Y., H. Kuan, C.-Y. Hung, and C.-S. Ye, "Design of dual-band bandpass filters using a dual feeding structure and embedded uniform impedance resonators," *Progress In Electromagnetic Research*, Vol. 105, 93–102, 2010.
20. Orfanidis, S. J., "A two-section dual-band Chebyshev impedance transformer," *IEEE Microwave and Wireless Components Letters*, Vol. 13, No. 9, 382–384, Sep. 2003.