on Communications

DOI:10.1587/transcom.2018EBP3145

Publicized:2019/02/12

This advance publication article will be replaced by the finalized version after proofreading.

A PUBLICATION OF THE COMMUNICATIONS SOCIETY

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Dual Polarized Cylindrical Loop Slot Antenna for Omni Cell Application

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SUMMARY Urban area suffers severe multipath effects due to its complex infrastructure environment and sector antenna is a popular choice as a base station antenna in those areas. Within sector antennas, omni cell antenna is utilized as supporting antenna to cover low reception areas between them. This paper proposes a slant $\pm 45^\circ$ dual polarized omnidirectional antenna to operate as the omni cell antenna in those environments. The frequency band covers the IMT band, ranging from 1920 MHz to 2170 MHz with directivity focusing in horizontal plane. The antenna structure consists of a loop slot antenna array as excitation element which is placed inside a cylindrical slot antenna as parasitic element. Good performance is achieved in both S-parameter and directivity results, with a gain of more than 4 dBi and a gain difference of less than 1.5 dB. The measurement results also agree well with the simulation results and the final design confirms that the proposed antenna works effectively as a slant $\pm 45^\circ$ dual polarized omnidirectional antenna.

key words: Cylindrical slot antenna, dual polarization, loop slot antenna, omni cell antenna, omnidirectional antenna, parasitic element.

1. Introduction

Urban area has high population density and due to the complex infrastructure environment, it suffers multipath effects in the propagation path. Sector antenna is widely used in densely populated area where base station can take advantage of the antenna capability of dividing the area on horizontal plane to improve the transmission speed and capacity [1]-[3]. However, there are areas within sectors with low reception intensity due to shadow regions created by buildings. At the same time, significant increases can be seen in communication traffic when the capacity content increases consequent to the surge of users using smart devices such as smart phones and tablets [4]. Omni cell is a practice of utilizing an antenna to cover small and local area with low receiving signals between sector cells, and against radio disturbance areas such as building shades. As of late, the omni cell system is fast becoming the cellular configuration to complement radio blind areas [5]-[6]. As

a counter measure for the rapid increase of data transmission capacity, high-density arrangement and high functionality of base station antennas are indispensable [7].

High function base station such as MIMO base station for example, often utilizes diversity techniques; spatial diversity and polarization diversity, with tilted or switched beam antennas to prevent cell interference to the aforementioned sector cells and adjacent cells [8]. In spatial diversity configuration, it is necessary to arrange two antennas at the designated antenna space, where the correlation between the elements is low; this appears problematic if the size of the base station is large. On the other hand, it is possible to integrate two antennas to have orthogonal polarizations in the polarization diversity configuration; where the installation space can be reduced while low correlation between elements can be obtained sufficiently. Hence, a base station especially for outdoor environment is often designed with the polarization diversity configuration to compensate for the deterioration of transmission characteristics due to fading. Furthermore, since the installation space is limited to elements like poles, smaller and thinner antenna is highly in demand. In short, there is a need for a low cost, easy to manufacture, compact base station antenna utilizing high performance omni cell system.

The required performance for an omni cell antenna includes omnidirectional radiation pattern on horizontal plane, where the area is covered horizontally in full 360° using just one antenna. The polarization diversity will provide the anti-fading measures under a multipath environment, preventing the decrease of received radio wave level due to the interference from multiple radio waves. The signals can be switched or synthesized by using orthogonal polarization elements. Many omnidirectional antenna structures for horizontal plane have been developed over the years. For a long time, half wavelength dipole antenna has been generally used as a vertically polarized omnidirectional antenna, while printed dipole antenna has been widely opted as current base station antennas because of its advantages, such as small size, small diameter and ease of antenna configuration [9]-[11]. However, horizontal loop antenna and notch antenna also have been proposed as horizontally polarized omnidirectional antennas [12]-

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[14]. A slant 45° linearly polarized wave is widely used in terrestrial communication, such as military and commercial uses because it has more contrasting propagation characteristic than vertical or horizontal polarization [15]. Many base station antenna structures for mobile communication with slant 45° polarization have been proposed, but most of them are antenna structures for sector cells covering an area of up to 120° in horizontal plane [16]-[20].

The low profile structure in [21] is a slant 45° antenna having a helical structure for the purpose of forming omnidirectional pattern. The proposed structure has the advantages of having no need for the ground plane with simple feeding structure but unfortunately in [22] it was demonstrated that it is actually a circularly polarized omni-directional antenna instead, hence it is not effective as 45° polarized omnidirectional antenna. The cross dipole cylindrical structure in [23] has four printed cross dipoles wrapped around a flexible dielectric cylinder, and a feeding circuit is arranged inside the cylinder. The cross dipoles are composed of a horizontal dipole and a vertical dipole and by adjusting the length of dipoles, it is possible to excite 45° polarized waves. Also, a balun circuit and a matching circuit are formed in feeding circuit. The gain difference is 1 dB or less, the gain itself is 0 dBi or less because of the beam width in vertical plane is 1.5 times that of the dipole antenna. Also, since it has a complicated feeding circuit, it is difficult to share polarizations.

The single feeding structure using parasitic elements in [24] has a probe that operates as a monopole, placed on a circular ground plane with eight tilted parallelepiped dielectrics as parasitic elements surrounding the feeding probe. The 45° polarization is excited by electromagnetically coupled the probe and the parasitic element. The maximum radiation direction for this antenna is not in horizontal plane ($\theta = 90^\circ$) but actually at $\theta = 38^\circ$ direction. The radiation is in the diagonally upward direction, and the level of radiation in horizontal plane is low, hence its usefulness as an omnidirectional antenna in horizontal plane is absent. Furthermore, since the elements are formed on the ground plane, it is difficult to share polarization. The polarization conversion structure in [25] has a biconical antenna wave surrounded by the multiscreen cylindrical polarizer, converting the monopolar omnidirectional vertically polarized wave into 45° slant-polarized wave. The polarization conversion elements are stacked in five layers where metal lines inclined at different angles are arranged in each layer. Although it has broadband characteristics produced by the biconical antenna, the gain is 0 dBi or less due to the large beam width. Also, it is difficult to realize the polarization sharing because the feeder circuit needs to be arranged outside the radiating element.

As a summary, those antennas are considered to

have the following problems;

(1) The feeding circuit is complicated thus it is difficult to arrange sharing element and feeding circuit for other polarized waves.

(2) Since ground plane is used, when the elements are stacked, the mutual ground plates interfere with radiation.

(3) For stacking of the elements, it is necessary to dispose a feeder circuit outside the antenna radiating element.

In view of the above in order to realize polarization sharing, a simple structure without using a ground plane is required. Furthermore, it is necessary to improve the gain by narrowing the beam width in vertical plane and produce the maximum radiation direction in horizontal plane ($\theta = 90^\circ$) instead.

This paper proposes a slant $\pm 45^\circ$ dual polarized omnidirectional antenna intended for omni cell application in a base station. The targeted frequency is for IMT band which range from 1920 MHz to 2170 MHz. The directionality for this antenna is omnidirectional in horizontal plane which cover several meter to several tens meter area. The gain different which is defined as the difference between the maximum gain and the minimum gain of the directivity in horizontal plane is an important evaluation index in the omni directionality and the targeted gain different is less than 3 dB. On the other hand, the gain must be more than 4 dBi while the antenna diameter of less than 0.4λ is proposed.

2. Antenna Structure Consideration

Omni directionality can be achieved using just a simple dipole antenna but mounting a dipole might not be as simple as the structure itself. A structure that can be easily mounted on utility pole or a wall of a building is considered, with the gain that should be higher than dipole antenna. In this section, the basic structure of the proposed antenna is considered and discussed.

2.1 Consideration of Cylindrical Slot Antenna

Any slot has its complimentary form in wire or strip where the pattern and impedance data of these forms can be used to predict the patterns and impedance of the corresponding slots [26]. Dipole antenna whose omni directionality can be achieved easily has the complimentary structure of a vertical slot cut on a perfect electric conductor (PEC) plane. To achieve slant 45° polarized wave, one simply needs to rotate the dipole tilted to 45° in angle and like so for its complementary slot. For a dipole antenna as a vertically excited element which is placed in the center of two dipoles or slots inclined at angle 45° as the parasitic elements, the radiated electric field of the dipole antenna can be decomposed into two components of $E_0/\sqrt{2}$ orthogonal to

each other. These component electric fields will excite the parasitic elements parallel to this electric field, thereby forming omni directionality in horizontal plane. Fig. 1 describes the principle theory of $\pm 45^\circ$ slant polarized wave using dipoles and its complementary relationship of slot antenna.

On the other hand, when two dipole which is placed in orthogonally crossed position at angle 45° with a quarter wavelength spacing are excited simultaneously with the same amplitude and same phase, circularly polarized waves are radiated in both directions on the array axis instead [27]. Therefore, it is necessary to set the condition to excite slant 45° linearly polarized waves by changing the axial ratio of the directivity according to the element spacing. For half wavelength dipole antenna, when the distance between dipole antenna and parasitic element is around $\lambda/4$, the parasitic elements are excited at the same amplitude and in the same phase, thus the axial ratio becomes 3 dB or less and radiates circularly polarized waves. Therefore, in order to excite slant 45° linearly polarized waves, it is necessary to make element interval narrower than $\lambda/4$ or wider. The same theory is applied for later design to produce slant 45° linearly polarized waves instead of circularly polarized wave.

Next, a slot which is cut slanted on a square PEC plane is considered to replace dipole antenna. When the slot is fed directly using offset feeding, omni directionality is achieved. However if the slotted PEC plane is rolled into a cylinder, the perfect omnidirectional pattern will distort due to the influenced of the cylinder as shown in Fig. 2(a). Therefore, the number of cut slot is increased and direct feeding is applied to the slots simultaneously using offset feeding in order to match the impedance easily. Fig. 2 shows the radiation pattern results in horizontal plane for different number of slots where it can be seen that the radiation pattern gradually approaching omnidirectional pattern. Omni directionality is obtained when 4 or more slots are used and cross polarization also can be seen improved as the number of slots increased. For the proposed antenna structure, cylinder with 4 slots is chosen in consideration for simpler feeding circuit.

Slot and dipole are known to radiate even when only one element is excited due to dual relationship between electric field and magnetic field. When a dipole is position perpendicularly to a slot, the non-excited dipole will radiates because the elements are electromagnetically coupled between each other [26]. An electrical current gives rise to the surrounding magnetic field and a magnetic field can also generate an electrical current. This dual relationship between electric and magnetic fields is the basic and fundamental physical property [28]. Therefore, one PEC plane with a height of λ mm is etched with 4 thin slots of 0.8λ in length inclined at angle 45° as shown in Fig. 3 is considered. The PEC plane then is rolled into a perfect cylinder

Fig. 1 Principle theory for slant 45° polarized wave dipole antenna and its complementary relationship slot antenna.

Fig. 2 Cylindrical slot antenna and its respective radiation pattern in horizontal plane at 1.9 GHz for (a) 1 slot, (b) 3 slots, (c) 4 slots and (d) 6 slots.

Fig. 3 Proposed design for cylindrical slot antenna. (a) A PEC plane with slots is (b) rolled into a cylinder.

Fig. 4 S-parameter and radiation pattern results for the cylindrical slot antenna at 2 GHz.

making a radius of 0.1λ . A half-wave dipole antenna is placed in the z-axis direction inside the cylindrical slot and instead of direct feeding to the slots, only dipole antenna is excited making the cylindrical slot element parasitic. The parameter studies of the proposed structure are simulated in CST software [29] at the frequency of 1.9 GHz. Fig. 4 shows the performance of the proposed antenna where good S-parameter results of below -10 dB at 2 GHz and the omni directionality with the gain of more than 2 dBi in horizontal plane has been obtained.

2.2 Consideration of Loop Slot Antenna

In previous section, the proposed design utilizing parasitic element produces omni directionality in horizontal plane but the gain is just a little bit higher than dipole antenna. And although dipole antenna has simple structure, printed dipole antenna is more popular choice as vertically polarized antenna as it has the advantage of wider bandwidth and small gain different and easier to fabricate. However, similar to dipole antenna, the printed dipole antenna also requires balun which will increase the antenna width greatly. On the other hand, microstrip array structure gives a wide band and high gain performance [30]-[31]. Taken that into consideration, a loop slot structure is considered instead, as it does not require balun thus will reduce the width incredibly. The proposed loop slot antenna shown in Fig. 5 uses a dielectric substrate of 0.8 mm in thickness with a relative dielectric constant of $\epsilon_r = 4.3$. The front side consists of a rectangle slot while on the back side consists of the microstrip feed line. Vertically polarized waves are excited by electromagnetically coupled the feed line on the back side with the loop side on the front side. The total length of the loop slot greatly affects the resonance frequency thus it is possible to match the impedance just by adjusting the slot width and the feed line width. In addition, since the structure is using dielectric substrate in the unbalance mode, the balun is not required thus the diameter of the substrate can be reduced.

Next, two parasitic elements in rectangular form are loaded on both sides of the substrate to improve the directivity and expand the bandwidth. The radiating element is excited by electromagnetically coupling the parasitic elements through the loop at the front and the feed line at the back. It is considered that unnecessary radiation can be suppressed by adopting a structure that separates the feeding circuit and the radiating element. Moreover by changing the distance of the parasitic elements on both sides accordingly, it is possible to improve the coupling thus further enhance the directivity. The impedance is matched at 2 GHz and the maximum gain obtained is 2.65 dBi which just a little bit higher than dipole antenna. Although from these results we can see that the reflection characteristic and the directivity in horizontal plane for printed dipole antenna and the loop

Fig. 5 The structure of loop slot antenna in (a) top view and (b) side view. [$w_d=0.5\lambda$, $l_d=0.6\lambda$, $t_d=0.8$, $w_s=0.15\lambda$, $l_s=0.24\lambda$, $g_s=w_f=0.01\lambda$, $l_1=0.07\lambda$, $l_2=0.25\lambda$, $d_1=0.057\lambda$, $d_2=0.069\lambda$, $h_1=0.07\lambda$, $h_2=0.36\lambda$, $h_3=0.18\lambda$] mm.

Fig. 6 Loop slot antenna array in (a) side view, (b) top view and (c) the 3D radiation pattern and current distribution for before and after cut out slot. [$w_d=0.17\lambda$, $l_d=1.4\lambda$, $t_d=0.8$, $w_s=0.1\lambda$, $l_s=0.24\lambda$, $g_s=w_f=0.01\lambda$, $l_1=0.22\lambda$, $l_2=0.48\lambda$, $d_1=0.057\lambda$, $d_2=0.069\lambda$, $h_1=0.07\lambda$, $h_2=0.36\lambda$, $h_3=0.54\lambda$] mm.

Fig. 7 S-parameter and radiation pattern in xy-plane results for loop slot antenna at 2 GHz.

slot antenna are substantially similar, the width of the loop slot antenna has been reduced to at least 1/3 less than if the printed dipole antenna with balun is used instead.

The structure of the loop slot antenna is then arrayed into two elements to improve the gain as shown in Fig. 6. Normally, an array has the same structure and same feeding point thus tournament feeding structure is usually considered where the arrayed slots are both fed from bottom [32]. However, tournament feeding method requires a space corresponding to the feeder line thus the lateral width of the antenna then will be increased. Therefore, an out of phase linear feed method which has been discussed in [33] is used instead to accommodate the required space. The out of phase linear feed line is a straight line in the middle of the substrate connecting the two slots on the back side which greatly reduce the width of the substrate. The power is supplied from the lower part to the upper element and from the upper part to the lower element, occurring reverse phase excitation when the power is supplied in the same phase. Thus, simultaneous excitation is carried out by performing reverse phase feeding from feed point $\lambda/4$ from the center.

The initial result of the reflection characteristic for the array structure shows a similar result as one element structure (black line in Fig. 7) but the gain in directivity improves only about 1 dB. Upon investigating the radiation pattern as shown in Fig. 6(c), it is found that the radiation in the horizontal plane around the loop slot in both upper and lower array has becomes larger while the radiation in the center of the structure has decrease slightly. According to current distribution result as shown in the same figure, unnecessary standing wave at the center of the structure has been generated, which is considered to be the cause that the directivity is distorted. Therefore, in order to remove the unwanted standing wave, a rectangle shape slot is cut from both sides in the very center of the structure giving an I-shaped structure. Fig. 6(b) shows the array antenna with cut out slot and Fig. 6(c) shows the 3D radiation pattern and current distribution at 2 GHz for before and after structure is changed. From the figure it can be confirmed that directivity is improved by removing unnecessary standing wave at the center of the structure. Fig. 7 shows the reflection characteristic covering the required bandwidth with good characteristics obtained at 2 GHz and the directivity with the gain of 4 dBi or less and the gain different of 1 dB or more has been obtained. Therefore the omnidirectional pattern has been obtained in horizontal plane at 2 GHz with small gain different. The bandwidth however is reduced at the matched frequency because the reflection is increased by coupling radiation from the lower loop slot to the adjacent feeder line from the electric field distribution. Thus the radiation in the y-axis direction is suppressed and the omni directionality cannot be achieved.

3. Cylindrical Loop Slot Antenna

In section 2, two structures are considered to obtain omni directionality in horizontal plane but the performance of

both suggested structures are not satisfactory. Cylindrical loop slot antenna achieves perfect omni directionality but the gain is just a little bit higher than dipole antenna. The loop slot antenna has the maximum gain of 4 dBi but omni directionality is disturbed. In this section, we investigate a slant 45° omnidirectional antenna by loading a parasitic cylindrical slot element around a loop slot antenna as the excitation source element to improve directivity and output gain of the proposed antenna.

3.1 Slant 45° Single Polarized Omnidirectional Antenna

The I-shaped loop slot antenna using out of phase linear feed structure without parasitic elements is considered as the excitation source and is placed inside the cylindrical loop slot structure. The combination structure as single polarization structure is shown in Fig. 8. The substrate has a relative dielectric constant of $\epsilon_r = 2.6$ and a thickness of 0.8 mm. The cylindrical with array slots has the height of 1.6λ to accommodate the arrayed excitation structure and gives the optimum performance at the radius of 0.15λ . The center to center distance of the slots is 0.8λ . And considering the actual feeding for fabrication purpose, coaxial cable is considered and is fed from bottom as the antenna is arranged in vertical direction. And as the structure is made as thin as possible to accommodate the required mounting condition, the inter-polarization coupling has to be considered. In order to avoid disturbance in directivity influenced by the electric field presents in the coaxial cable, the coaxial outer layer has to be grounded by connecting to the ground side of the dielectric substrate. Therefore the unnecessary electric field of the outer layer of the coaxial

Fig. 8 Geometry of the proposed slant 45° single polarized omnidirectional antenna with S-parameter and radiation pattern comparison between the excitation sources; with and without cylindrical slot.

cable is removed. The grounding process is essential in improving the directivity in the horizontal plane.

The results in Fig. 8 show performance comparison when only loop slot antenna is excited (no cylinder) and when loop slots antenna loaded with parasitic cylindrical slot (with cylinder) is excited. The S-parameter result shows that one resonance is nicely achieved at 2 GHz when excitation source is loaded into the cylinder (red line) as compared with only excitation source without the cylinder (black line). The radiation pattern that is originally a little bit directional in $\pm 90^\circ$ (black line) is improved to omnidirectional for with cylinder (red line) with the maximum gain improved from 4 dBi to 5.2 dBi and with the gain different of 1.2 dB. As a result, the resonance occurs in the desired bandwidth and it can be confirmed that the polarization of the omni directionality at slant 45° is improved by using I-shaped loop slot antenna loaded with parasitic cylindrical slot antenna.

3.2 Slant $\pm 45^\circ$ Dual Polarized Omnidirectional Antenna

Single polarized omnidirectional antenna has been achieved by placing the loop slot antenna inside the cylindrical slot antenna. Conveniently, dual polarization can easily be obtained by adding another array of the excitation element and thus extends the cylinder heights to 2.4λ to accommodate the added structure. The angle of the slots in the top side is in the opposite direction from the bottom side of the cylinder, giving the symmetrical structure from the center. It is very important to maintain the radius of the cylinder as it controls the impedance to be matched at the resonance frequency. The center to center distance between two excitation sources is one λ and the -45° and $+45^\circ$ polarizations are excited by the top side and bottom side of the excitation element, respectively. The coaxial cable feeding for the -45° polarized wave is connected to the dielectric ground of the $+45^\circ$ excitation element. Port 1 excites the bottom side of the loop slot array while port 2 excites the top side, as illustrated in Fig. 9(a). In term of the inter-polarization coupling, there are two current paths to be coupled. One is through the cylinder and the other one is through the outer layer of the coaxial cable feeding the upper element. Therefore, in order to alleviate these problems, the structure of connecting the outer layer of the coaxial cable to the cylinder is considered. Since the current flowing through the outer layer flows into the cylinder which is a perfect conductor whose conductivity is higher than the dielectric, coupling via the coaxial cable can be reduced. Thus, by connecting the outer layer of the coaxial cable and the cylinder, coupling between the polarized waves inside the cylinder is suppressed, as well as the excitation of the orthogonal slot on the cylinder.

Fig. 10 shows the S-parameter and directivity results comparing when the outer layer of the coaxial

Fig. 9 (a) Geometry for the proposed slant $\pm 45^\circ$ dual polarized omnidirectional antenna showing the connector fixed to the cylinder. (b) Photo of the fabricated antenna.

Fig. 10 Simulation result for s-parameter and radiation pattern comparison for before connecting and after connecting the outer layer of the coaxial cable to the cylinder.

Fig. 11 S-parameter and radiation pattern comparison between simulation and measurement results.

cable is before grounded and after grounded by connecting to the substrate ground side. The S_{21} at 2 GHz for when the outer layer is grounded (solid line) reads at -20.5 dB while for when not grounded is higher at -13.5

dB. From this result, it is confirmed that the inter polarization coupling occurs via coaxial cable outer layer and has been suppressed. The directivity of the ungrounded structure is a little bit disturbed when port 1 is fed due to the fact that unnecessary radiation is generated by electromagnetic coupling between the coaxial cable and the loop slot. However, when the coaxial cable is grounded, the electromagnetic coupling does not occur thus the directivity is improved.

The reflection characteristic for the final structure as shown in Fig. 10 (solid line) covers the desired band with good reflection characteristic obtained for both polarized waves, and the inter-polarized coupling has been reduced to less than -20 dB at frequency 2 GHz. The S_{21} is at -20.2 dB and more than -30 dB at the lower side frequency and higher side frequency, respectively. The gain at frequency 1.92 GHz are 4.4 dBi and 4.0 dBi for $+45^\circ$ and -45° , respectively and at 2.17 GHz are 4.6 dBi and 4.5 dBi, respectively. Thus, a slant $\pm 45^\circ$ dual polarized omnidirectional antenna with a gain of more than 4 dBi and the gain different of less than 1.5 dB has been obtained.

4. Fabrication and Measurement

In this section, the slant $\pm 45^\circ$ dual polarized omnidirectional antenna discussed in the previous section is fabricated to confirm the antenna performances. As in the simulation, the coaxial cable outer layer is grounded to the cylinder to suppress the inter polarization coupling. A copper plate with a thickness of 0.01 mm is used for the parasitic cylindrical slot element, and the excitation element is fixed by using the foam. The fabricated structure is shown in Fig. 9(b). Comparison of the S-parameter results between the simulation result and measurement result is shown in Fig. 11, as well as the comparison for directivity results which achieve a good agreement between simulation and measurement results.

The proposed antenna covers desired band range from 1.92 GHz to 2.17 GHz with good S_{11} reading below -10 dB. The S_{21} for measurement result is comparable with the simulation result, obtaining the inter polarization coupling of less than -20 dB. The directivity is omnidirectional in horizontal plane with just a little disturbance as compared with simulation result but with maximum gain of 4 dBi or more and gain difference of 1.5 dB or less for both $\pm 45^\circ$ polarizations. The bandwidth covers the desired bandwidth for IMT band ranging from 1920 ~ 2170 MHz where for simulation and measurement results, a bandwidth of 11.8% (240 MHz) and 19.1% (370 MHz) has been achieved, respectively. As a result, a novel slant $\pm 45^\circ$ dual polarized omnidirectional antenna composing of loop slot antenna arrays placed inside parasitic cylindrical slots structure with good antenna performance has been obtained.

4. Conclusion

This paper proposed a $\pm 45^\circ$ dual polarized omnidirectional antenna intended for omni cell application in high function base station. By placing a loop slot antenna as the excitation element inside a parasitic cylindrical slot element, a slant 45° single polarized omnidirectional antenna with a gain of more than 4.5 dBi and a gain difference of 1 dB or less is excited in the IMT frequency band ranging from 1920 MHz to 2170 MHz. The coaxial cable is used as a feeding line and by grounding it to the ground side of the dielectric substrate, it is possible to obtain a gain of not less than 5 dBi and a gain difference of not more than 1.5 dBi in the simulation. Conveniently, dual polarization can be achieved easily by adding another similar array of the excitation element where good reflection characteristic has been achieved covering the intended frequency range. The inter-coupling polarization is sufficiently suppressed to be less than 20 dB within the band range by connecting the coaxial cable outer layer to the cylinder. The omni directionality is obtained in the horizontal plane with a gain of 4 dBi or more and a gain difference of 1.5 dB or less. The measurement results agree well with the simulation results, confirming that the parasitic cylindrical slot antenna using the loop slot antenna as the excitation element proposed in this paper is effective as the slant $\pm 45^\circ$ dual polarized omnidirectional antenna.

Acknowledgments

This work is partly supported by KMW Inc.

References

- [1] J. E. Mitzlaff, "Radio propagation and anti-multipath techniques in the WIN environment," IEEE Network, vol. 5, no. 6, pp. 21-26, November 1991.
- [2] J. -F. Pintos, A. Louzir, P. Minard, and D. L. H. Tong, "Ultra compact multi-sector antenna system using retro-directive array concept," 2011 IEEE International Symposium on Antennas and Propagation (APSURSI 2011), Spokane, WA, pp. 1211-1214, July 2011.
- [3] N. Honma, T. Seki, and K. Nishikawa, "Compact planar four-sector antenna comprising microstrip yagi-uda arrays in a square configuration," IEEE Antennas and Wireless Propagation Letters, vol. 7, pp. 596-598, May 2008.
- [4] Copyright Cisco The Network, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016-2021 White Paper, <https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html>, accessed November 2017.
- [5] I. Ichiro and H. Yagi, "2 GHz band dual polarized omnidirectional antenna," Proceeding of IEICE Society Conference, vol. B-1-149, 2003.
- [6] H. Kakehuda, A. Shimamura, T. Tanaka and Y. Ebina, "A design method of dual polarized omni-directional antenna for radio blind area," Proceeding of IEICE Society Conference, vol. B-1-79, 2009.

- [7] D. G. Steer, "High density cellular communication using radio aperture synthesis," 2015 IEEE International Conference on Communication Workshop (ICCW), London, pp. 2151-2156, June 2015.
- [8] J. G. Andrews, W. Choi and R. W. Heath JR., "Overcoming interference in spatial multiplexing MIMO cellular networks," IEEE Wireless Communications, vol. 14, no. 6, pp. 95-104, December 2007.
- [9] Wu Di, Yin Yingzeng, Guo Minjun and Shen Renqiang, "Wideband dipole antenna for 3G base stations," 2005 IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications, vol. 1, pp. 454-457, 2005.
- [10] W. X. An, H. Wong, K. L. Lau, S. F. Li and Q. Xue, "Design of broadband dual-band dipole for base station antenna," IEEE Transactions on Antennas and Propagation, vol. 60, no. 3, pp. 1592-1595, March 2012.
- [11] Y. Gou, S. Yang, J. Li and Z. Nie, "A compact dual-polarized printed dipole antenna with high isolation for wideband base station applications," IEEE Transactions on Antennas and Propagation, vol. 62, no. 8, pp. 4392-4395, August 2014.
- [12] X. Quan, R. Lin, J. Wang, and Y. Cui, "Development of a broadband horizontally polarized omnidirectional planar antenna and its array for base station," Progress In Electromagnetics Research, vol. 128, pp. 441-456, 2012.
- [13] K. Wei, Z. Zhang, Z. Feng, and M. F. Iskander, "A MNG-TL loop antenna array with horizontally polarized omnidirectional patterns," IEEE Transactions on Antennas and Propagation, vol. 60, no. 6, pp. 2702-2710, June 2012.
- [14] H. Arai and K. Takahashi, "Design of horizontally polarized omni-directional antenna by characteristic modes analysis," 2016 IEEE International Symposium on Antennas and Propagation (APSURSI), Fajardo, pp. 3-4, June 2016.
- [15] B. Lindmark and M. Nilsson, "On the available diversity gain from different dual-polarized antennas," IEEE Journal on Selected Areas in Communications, vol. 19, no. 2, pp. 287-294, February 2001.
- [16] Y. Cui, R. Li and H. Fu, "A broadband dual-polarized planar antenna for 2G/3G/LTE base stations," IEEE Transactions on Antennas and Propagation, vol. 62, no. 9, pp. 4836-4840, September 2014.
- [17] R. Wu and Q. X. Chu, "A broadband dual-polarized butterfly antenna for base stations," 2016 IEEE International Conference on Computational Electromagnetics (ICCEM), Guangzhou, pp. 304-306, February 2016.
- [18] Y. He, Y. Yue and Z. Shen, "A novel broadband dual-polarized antenna element for LTE/700 MHz/GSM850 MHz/GSM900 MHz applications," IEEE Access, vol. 4, pp. 4321-4326, August 2016.
- [19] K. Gosalia and G. Lazzi, "Reduced size, dual-polarized microstrip patch antenna for wireless communications," IEEE Transactions on Antennas and Propagation, vol. 51, no. 9, pp. 2182-2186, September 2003.
- [20] V. F. Fusco and P. H. Rao, "Wide-band dual slant linearly polarized antenna," IEEE Transactions on Antennas and Propagation, vol. 51, no. 8, pp. 2014-2019, August 2003.
- [21] M. Amin, R. Cahill and V. Fusco, "Single feed low profile omnidirectional antenna with slant 45° linear polarization," IEEE Transactions on Antennas and Propagation, vol. 55, no. 11, pp. 3087-3090, November 2007.
- [22] S. Iqbal, M. Amin and J. Yousaf, "Low profile circularly polarized side-fed bifilar helix antenna," 2012 9th International Bhurban Conference on Applied Sciences & Technology (IBCAST), Islamabad, pp. 325-328, January 2012.
- [23] X. Quan, R. Li, Y. Fan, and D. E. Anagnostou, "Analysis and design of a 45° slant-polarized omnidirectional antenna," IEEE Transactions on Antennas and Propagation, vol. 62, no. 1, pp. 86-93, January 2014.
- [24] Y. M. Pan, S. Y. Zheng and B. J. Hu, "Singly-fed wideband 45° slant-polarized omnidirectional antennas," IEEE Antennas and Wireless Propagation Letters, vol. 13, pp. 1445-1448, July 2014.
- [25] A. Dastranj and B. Abbasi-Arand, "High-performance 45° slant-polarized omnidirectional antenna for 2-66-GHz UWB applications," IEEE Transactions on Antennas and Propagation, vol. 64, no. 2, pp. 815-820, February 2016.
- [26] J.D. Kraus and R. J. Marhefka, "Slot, patch and horn antennas," in Antenna: For All Applications, 3rd Ed. McGraw-Hill, ch. 9, sec. 9-1, pp. 304-307, New York, 2003.
- [27] Koichi Sakaguchi, Tohru Hamaki and Nozomu Hasabe, "A circularly polarized omnidirectional antenna," IEICE Transaction Communication, vol. E79-B, no. 11, pp. 1704-1710, November 1996.
- [28] K. Itoh, I. Shibusaki and T. Matsumoto, "Investigation of an antenna system composed of slot and wire antenna," IEEE International Symposium on Antenna and Propagation, A-10-5, August 1978.
- [29] Copyright CST-Computer Simulation Technology, <https://www.cst.com/>, accessed December 2017.
- [30] H. D. Chen, C. Y. D. Sim, J. Y. Wu and T. W. Chiu, "Broadband high-gain microstrip array antennas for WiMAX base station," IEEE Transactions on Antennas and Propagation, vol. 60, no. 8, pp. 3977-3980, August 2012.
- [31] C. F. Huang and W. Y. Chen, "A wideband microstrip array based on air substrate for wireless base-station applications," 2013 7th European Conference on Antennas and Propagation (EuCAP), Gothenburg, pp. 1268-1271, April 2013.
- [32] K. Sakakibara, A. Kunita, D. Kawase, N. Kikuma, H. Hirayama and K. Seo, "Broadband millimeter-wave microstrip comb-line antenna using corporate feeding system," 2011 41st European Microwave Conference, Manchester, pp. 902-905, 2011.
- [33] R. Kaneda and H. Arai, "Vertically polarized omni-directional loop slot array antenna for mobile base station," IEICE Communications Express (ComEX) vol. 6, no. 6, p.p. 254-258, February 2017.

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