A Novel Printed Array Contoured Beam Antenna on HAPs

Ali Araghi
Electrical Eng. Dep.
Shahed University
Tehran, Iran
a.araghi@shahed.ac.ir

Hamid Reza Hassani
Electrical Eng. Dep.
Shahed University
Tehran, Iran
hassani@shahed.ac.ir

Faraz Maleknia
Iranian Research Institute
for Electrical Eng.
Tehran, Iran
fm.ieee@gmail.com

Ali Mohammad Montazeri
Sattelite Com. Dep.
Research Institute for ICT
Tehran, Iran
montazeri@itrc.ac.ir

***Abstract*— In this paper, a novel microstrip array antenna to achieve some specific contoured beam is presented. The proposed antenna produces three directional main beams which is a consequence of its particular layout. The antenna is suggested to be mounted on High Altitude Platforms (HAPs) to provide the desirable coverage (e.g. three separated islands). Using developed software, enables us to obtain the footprint of antenna on the ground. Furthermore, a study on channel capacity enhancement, employing the proposed antenna is carried out which clarify the profit of using this contoured beam antenna.**

Keywords-component; Contoured Beam Antenna, Microstrip Array Antenna, Coverege, Channel Capacity.

I. INTRODUCTION

Contoured beam antennas are generally applicable to provide an efficient coverage of the service area which are mostly used in geostationary satellite communication systems [1], i.e. antennas having a specific shaped main beam in order to its footprint on the ground follows the contour of desirable geographical region. The most significant issue in such kind of communication is to cover an area efficiently so that the desired zone be under coverage without causing any interference to other parts of communication network. The inevitable importance of this subject results in vast of research on proposing different ways to obtain a contoured beam antenna which are mostly related to reflector antennas [2]. Apart from the aforementioned, the main reason of using satellites to provide contoured beams is due to the specific behavior of transmitted wave through the propagation in such kind of communication systems. The connection link in these channels is mostly Line of Sight (LoS) and under this circumstance traveling waves often experience path loss and other propagation behaviors e.g. reflection, diffraction, and scattering are negligible. In this condition a cross section of radiation pattern is printed on the ground, so if the radiation pattern has been shaped before, the proper contour of coverage would be appeared on the ground. However, satellites extremely suffer from implementation and maintenance cost and also significant losses through the connection link which make them inconvenience to use in most of the communication systems as they need high propagation power in both sides of the link and also complicated devices for transmitter and also the receiver (e.g. high gain antennas, high gain low noise amplifiers, sophisticated processors, and etc). On the other hand using contoured beam antennas in terrestrial networks seems impossible because of the numerous unpredictable wave behaviors in such kinds of channels which mostly create a Non Line of Sight (NLoS) connection link between transmitter and the receiver.

High Altitude Platforms (HAPs) are either airship or aircraft which are both commonly taken place in stratosphere, 17km to 22km above the earth line [3]. The most promising standard on which HAPs communication is achievable is IEEE 802.16-SC [4], with modifications being largely confined to the base station in order to cope with HAPs mobility and the centralized cell structure. The standards were developed for frequency bands from $10-66$ GHz [5].

From radio propagation environment's aspect, the frequencies above 10 GHz will in general require LoS path and be increasingly prone to rain attenuation. Bands bellow 10 GHz can be operated increasingly as NLoS paths as the frequency is decreased, but will be prone to attenuation due to shadowing and multipath [3].

The two most common frequency bands allocated to HAPs are $47/48$ GHz and $31/28$ GHz with 300 MHz bandwidth in both uplink and downlink directions [3]. However, according to abovementioned IEEE standard alongside the radio propagation environment issues, other frequencies including 10 GHz and above (up to 66 GHz) can also be appropriate options to be utilized, so it follows that many attentions have been spent on this subject recently [3, 8].

As a result of the high altitude of these platforms's placement, the main part of connection link is LoS and it seems these platforms are appropriate choice for implementing the contoured beam antenna on them. Furthermore, maintenance cost of these systems is much less than satellites according to their simplicity and lower elevation. Aside from all mentioned merits of these platforms, the most significant demerit of them is their limited supportable weight of equipments to carry since they are placed inside the atmosphere and experience the gravity. Therefore, overweight reflector antenna should not be used in HAPs stations. Moreover, their relevant high gain is inessential in such systems.

Microstrip antennas, due to their attractive advantages of low profile, light weight, and etc are widely used for both military and commercial purposes. The numbers of research which have been carried out on them are numerous. However, here we are going to use a particular configuration of them to provide a specific contoured beam from a HAP transmitter.

978-1-4673-2073-3/12/$31.00 ©2012 IEEE

The antenna operates at 10 GHz to meet the requirement of discussed issues (IEEE standards and radio propagation environment) of a HAP system.

The reminder of this paper is organized as follows. In section II, the importance of using contoured beam antennas on HAPs in some specific situations is declared and after that it is clarified that for this mentioned situation, a particular antenna is required. Section III is devoted to the antenna design and in section IV the coverage's contour plot of the proposed antenna is presented. Moreover in this section, a study on channel capacity analysis is carried out to make it clear how the proposed contoured beam antenna can be effective from this aspect in comparison with using some conical beam antenna.

II. Definiiton of Problem and its Solution

In many parts of the earth, there are some closely but separated islands surrounded by water which in them life is led by human being. To provide communication services in such kinds of regions, it seems that there are two options: using a single transmitter so that cover all the area included water covered and main lands, or to use number of transmitters as much as the number of islands. In the first approach, noticeable amount of radiating energy is wasted to provide coverage for unnecessary zones (e.g. water). Moreover, in the second way, increasing the number of islands and so the transmitters, results in a definite increase in probability occurrence of unpleasant network issues (e.g. interference, network maintenance, and etc).

The idea to cope with these difficulties is presented at a glance in Fig. 1. Using HAP with specific antenna can be helpful. The antenna must have multi directional radiation pattern to cover such kinds of regions in an efficient way.

III. Antenna Design

Considering three islands 10km apart from each other extended in a straight-line, an antenna with three directional main beams is required. Each beam for covering an island and nulls of radiation pattern should be faced with water covered area. Under this circumstance, if the airship were placed at altitude of 22km above the ground plane, the angle difference between beams would be at about $20°$. To attain these properties, our proposed microstrip array antenna structure is illustrated in Fig. 2. As it is seen this antenna consists of three main components: a couple of linier array of five elements series- fed rectangular patch which is presented by black dashed line, the central meanderline specified by red pale dashed line, and the phase shifter which is distinguished by white dashed line. The proposed layout is printed on a 12×12 cm semi-square shape Rogers RT/ duroid5880 substrate with permittivity of $\varepsilon_r = 2.2$ and thickness of 0.158 cm. The resonance frequency is 10 GHz and the dimensions of each rectangular patch are the same as a conventional rectangular patch one at this frequency i.e. $Lp = 0.906$ cm, $Wp = 1.186$ cm [6]. The length of transmission line between each patch is equal to $\lambda_g / 2$ of a 100Ω line $Lf = 1.11$ cm and therefore its width is $Wf = 0.15$ cm. Such high amount of impedance is required in series- fed microstrip array design [6, 7]. The bent line Lb has length of $3\lambda_g / 4$ and $Lft = 8\lambda_g / 2$. There is also a 50Ω feedline at the corner of substrate with width of $Wmf = 0.5$ cm attached to a 3dB power divider. The length of *Horizontal* and *Vertical lines* is not necessary to be fixed at a specific constant value and only depend on physical characteristic of structure. However, in this specific design, a $180°$ phase shifter at the end of *Vertical line* is essential. According to inverse direction of each array arm from the excitation point of view, this phase shifter is necessary to make two arms inphase. To have a clear

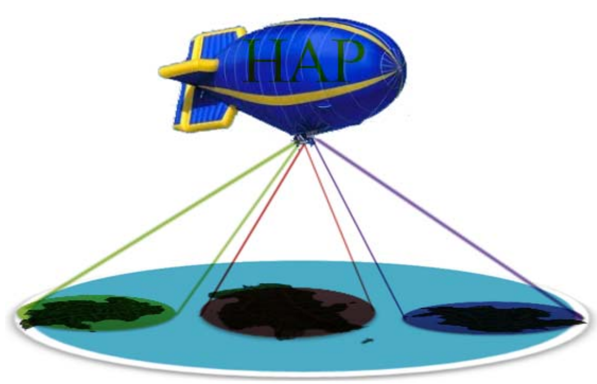

Fig. 1 Providing the coverege from a HAP using an antenna with more than one directional main beam.

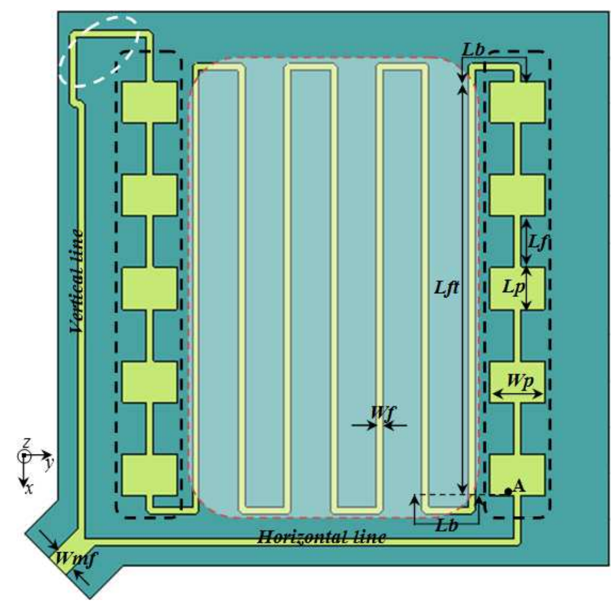

Fig. 2 The proposed antenna structure.

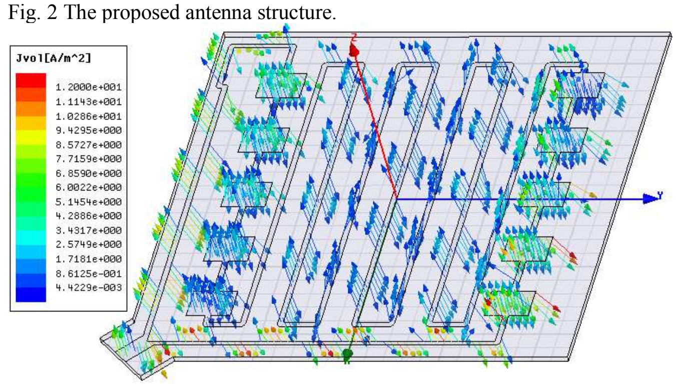

Fig. 3 Current distribution on the proposed antenna at 10GHz.

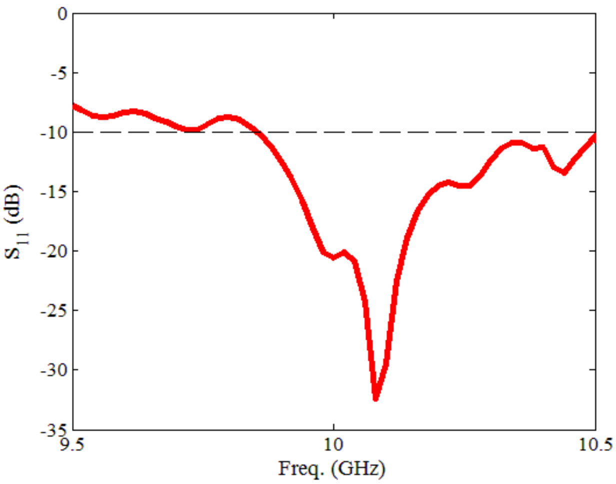

Fig. 4 Scattering parameter of the proposed antenna.

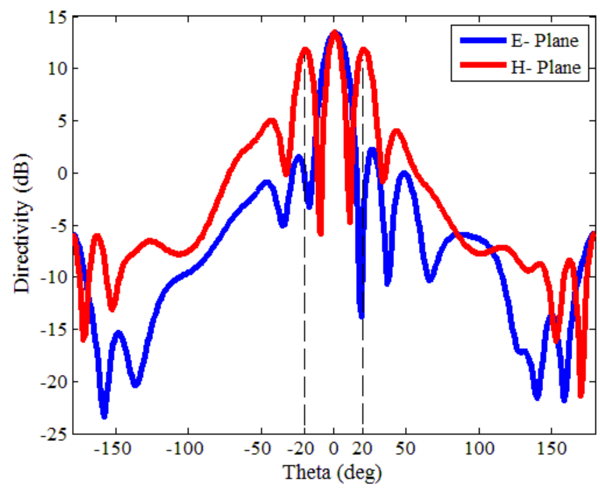

Fig. 5 Radiation pattern of the proposed antenna at 10GHz.

picture about the operation of antenna, it is beneficial to point out how wave behaves during the propagation on structure's body. Whenever the wave is reach to the point **A**, the radiation of right array is started. During the traveling on this arm, the wave amplitude is attenuated and after that, the wave amplitude is even more attenuated in meanderline. Such behavior in this structure results in an electrical tilting of this arm array's radiation pattern from boresight to positive y direction. The same behavior is occurred in the left array arm which ends up another tilting of radiation pattern to negative y direction. Apart from these, since both array arms have been inphased (because of the phase shifter), additive wavefronts in xz plane results in third beam directed to the boresight. In Fig. 3 a representation of current distribution on structure is shown and clarifies the mentioned properties. The simulation has been done using commercial full wave package Ansoft HFSS. It is also worth to mention that the existence of meanderline in the structure is obviously indispensable since illumination of this component results in two separated linier arrays far apart more than λ and under this circumstance, unwanted grating lobes occur. Using this meanderline enables us to control the radiation behavior as clarified before. The number of meanderline bents is optimized to attain two 20° tilted beams in $\pm\theta$ (to positive and negative direction of y axis).

Scattering parameter of structure is obtained as presented in Fig. 4 and its radiation pattern is shown in Fig. 5. As it is clear from Fig. 4, the structure is matched well at 10 GHz and three directional main beams to boresight and to $\theta = \pm 20°$ are attained in H-Plane (Fig. 5). Increasing the number of elements in array arms makes the E-Plane pattern narrower and here, we have chosen five elements for array arm to match the antenna footprint to some elliptical shape geographical contour.

IV. Results

In this section, to represent the results, at first the footprint of the proposed antenna on the ground is acquired, and after that a study on capacity enhancement in comparison with uniform coverage of islands is fulfilled.

A. Coverage Contour Plot

A software tool has been developed to obtain the coverage. By installing the proposed antenna on HAP at altitude of 22 km above the earth line, the footprint of radiation pattern on the ground at frequency of 10 GHz has been calculated as presented in Fig. 6. The channel model is HAP based Lazgare-Penin [8] and other parameters in calculating the link budget are selected as presented in TABLE I. The average building height of islands and also the street width is assumed to be 10 m. These values almost simulate the real probable case in view of this fact that such islands usually have not a dense layout of buildings. As it is observed, the antenna footprint is matched well to desirable geographical contour.

TABLE I. Link Budget Calculating Parameters

Parameter	Transmitted power	Receiver gain	Total extra losses
Value	41dBm	0dB	13dB

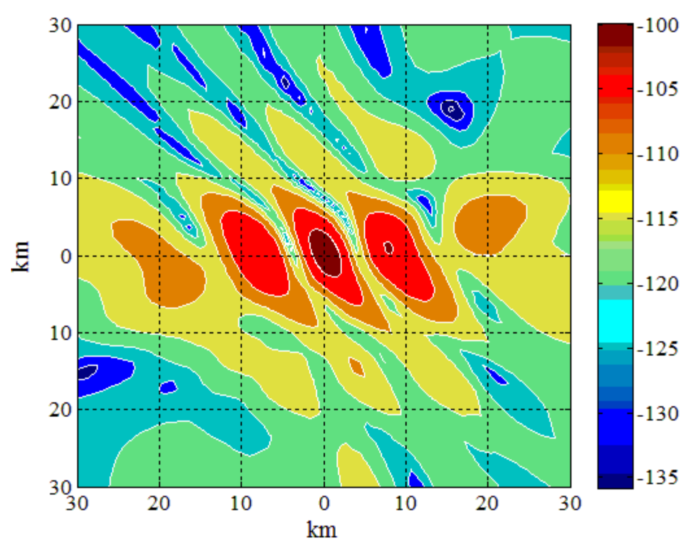

Fig. 6 Coverage contour of power (dBm) of the proposed antenna mounted on a HAP at altitude of 22km above the ground.

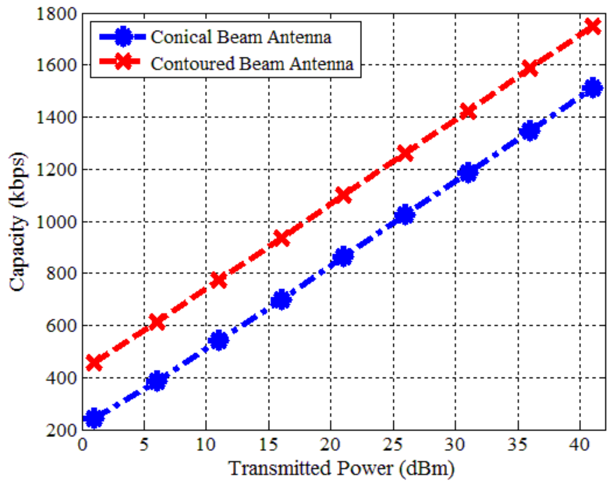

Fig. 7 Maximum expected channel capacity in islands.

B. Cahnnel Capacity Analysis

To make a clear picture on how well the proposed antenna can results in enhancement on channel capacity, two radiation scenarios are considered to cover the aforementioned islands. First is to employ the proposed antenna, and second is to use an arbitrary conical beam antenna which creates some circular shape footprint on the ground. In the second scenario the radiation power is equally devoted on both islands and water covered areas, so some amount of that is wasted.

Based on the proposed antenna footprint on the ground (1st scenario), channel capacity analysis has been studied in comparison with an arbitrary conical beam antenna (2nd scenario). The radius of –110 dBm border of circular shape coverage on the ground is 13km in the 2nd scenario at 41dBm transmitted power. In numerical calculations for maximum expected channel capacity, it has been assumed to have 100kHz spectrum band-width along with ambient temperature of 27°C. Three separated elliptical shape islands, extended in a straight-line with equal area of 40km^2, apart from each other by distance of 10km have been considered as the desirable zone to provide network coverage. Maximum expected channel capacity with respect to signal strength as a function of transmitted power, in both radiation scenarios is calculated as illustrated in Fig. 7. The aforementioned channel capacity is obtained using Shannon-Hartley theorem [9] with considering uniformly distributed of network usage around the islands. It is observed that the proposed antenna can increase the channel capacity of 2nd scenario at about 200kbps with respect to equal transmitted power in both radiation scenarios.

V. Conclusion

A specific structure of microstrip array antenna has been proposed to use for achieving some particular contoured beam. Due to lightweight of such kinds of antennas, the presented antenna structure can be used in High Altitude Platforms (HAPs) without any concern about the platform's shipment weight restrictions. The proposed antenna produces three directional main beams which can be applied to make the coverage of three separated islands. The footprint of antenna on the ground has been calculated using developed software and a discussion on how such structure can be beneficial from service's capacity point of view has been performed.

References

[1] I. Zaghloul, Y. Hwang, R. M. Sorebello, and F. T. Assal, "Advanced in multibeam communications sattelite antennas," *Proceedings of the IEEE*, vol. 78, no. 7, pp. 1214-1232, July 1990.

[2] D. W. Duan, Y. Rahmat-Samii, "A generalized diffraction synthesis technique for high performance reflector Antennas" *IEEE Trans. Antenn. Propagat.*, vol. AP-43, no. 1, pp. 27-40 ,Jan. 1995.

[3] D. Grace, and M. Mohorcic, "Broadband communications via high altitude platforms," John Wiely and Sons publication, chap. 2, 2011.

[4] IEEE 802.16e-2005 and IEEE 802.16-2004/Cor1-2005, Part 16, "Air Interface for Fixed and Mobile Broadband Wireless Access Systems Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1," IEEE, February 28, 2006.

[5] D. Grace, K. Katzis, D. A. J. Pearce, P. D. Mitchell, "Low-Latency MAC-Layer Handoff for a High-Altitude Platform Delivering Broadband Communications", *Radio science bulletin.*, no. 332, pp. 39-49, Mar 2010.

[6] C. A. Balanis, "Antenna theory, analysis and design", Chap. 14. *John Wiley and Sons*, 2005.

[7] R. Garg, P. Bhartia, I. Bahl, A. Ittipiboon, "Microstrip antenna design handbook", Chap. 12. *Artech House*, 2001.

[8] I. R. Palma-Lazgare, and J. A. Delgado-Penin, "Wimax HAPs-based downlink performance employing geometrical and statistical propagation channel characteristics", *Radio science bulletin.*, no. 332, pp. 50-66, Mar 2010.

[9] C. Shannon, "The zero error capacity of a noisy channel", *IRE Trans. Inf. Theory.*, vol. 2, pp. 8-19, Sept. 1956.