View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Research Online

UNIVERSITY OF WOLLONGONG AUSTRALIA

University of Wollongong
Research Online

Faculty of Engineering and Information Sciences - Papers: Part A

Faculty of Engineering and Information Sciences

2016

Dipole antenna array cluster for CubeSats

Sining Liu
University of Wollongong, sl527@uowmail.edu.au

Raad Raad
University of Wollongong, raad@uow.edu.au

Kwan-Wu Chin
University of Wollongong, kwanwu@uow.edu.au

Faisel Em M Tubbal
University of Wollongong, femt848@uowmail.edu.au

Publication Details

S. Liu, R. Raad, K. Chin & F. EM. Tubbal, "Dipole antenna array cluster for CubeSats," in 10th International Conference on Signal Processing and Communication Systems (ICSPCS), 2016, pp. 1-4.

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Dipole antenna array cluster for CubeSats

Abstract
CubeSats are attracting interest from both the industry and academia because of their affordability. Specifically, they are made from commercial Off-The-Shelf (COTS) electronic circuit chips, and are thus seen as a cost effective replacement for traditional, expensive satellites. Moreover, they are expected to have higher capabilities to better support demanding missions. To date, most CubeSats rely on a single element antenna that usually has a relatively low gain and are not steerable. Thus, they are not suitable for long-distance communications and for use by missions requiring high-speed links and adjustable radiation patterns. Existing single element antennas also increase the probability of failure when establishing communication links, as the failure of the single element would lead to a disconnection. In this paper, we propose a 3x1 dipole antenna array and a cluster of three 3x1 dipole antenna arrays for CubeSats. Each array can theoretically be used on a separate frequency. Advantageously, all three arrays can be combined to enhance directivity. Our simulation results show that the proposed antenna cluster has a high gain of 5.03dB and wide directivity.

Keywords
array, dipole, cluster, cubesats, antenna

Disciplines
Engineering | Science and Technology Studies

Publication Details
S. Liu, R. Raad, K. Chin & F. EM. Tubbal, "Dipole antenna array cluster for CubeSats," in 10th International Conference on Signal Processing and Communication Systems (ICSPCS), 2016, pp. 1-4.

This conference paper is available at Research Online: http://ro.uow.edu.au/eispapers/6391

Dipole Antenna Array Cluster for CubeSats

Sining Liu[1], Raad Raad[1], Kwan-Wu Chin[1], Faisel EM Tubbal[1,2]

[1]School of Electrical, Computer and Telecommunications Engineering, University of Wollongong, NSW, Australia, 2522
[2]Technological Projects Department, the Libyan Center for Remote Sensing and Space Science, Tripoli, Libya
sl527@uowmail.edu.au,{raad, kwanwu}@uow.edu.au,femt848@uowmail.edu.au

***Abstract*—CubeSats are attracting interest from both the industry and academia because of their affordability. Specifically, they are made from commercial Off-The-Shelf (COTS) electronic circuit chips, and are thus seen as a cost effective replacement for traditional, expensive satellites. Moreover, they are expected to have higher capabilities to better support demanding missions. To date, most CubeSats rely on a single element antenna that usually has a relatively low gain and are not steerable. Thus, they are not suitable for long-distance communications and for use by missions requiring high-speed links and adjustable radiation patterns. Existing single element antennas also increase the probability of failure when establishing communication links, as the failure of the single element would lead to a disconnection. In this paper, we propose a 3x1 dipole antenna array and a cluster of three 3×1 dipole antenna arrays for CubeSats. Each array can theoretically be used on a separate frequency. Advantageously, all three arrays can be combined to enhance directivity. Our simulation results show that the proposed antenna cluster has a high gain of 5.03dB and wide directivity.**

Keywords—CubeSat; antenna array; CubeSat swarm; cooperative communications; deep space.

I. Introduction

CubeSats are a class of pico-satellites that have become increasingly popular in academia and amongst hobbyists. This is because of the following advantages. CubeSats are small, lightweight and have the ability to form a swarm that allow them to communicate directly with one another easily. The smallest CubeSat has a dimension 10cm×10cm×10cm (1U) and has a mass of 1.3 kg. They can also be 10cm×10cm×20cm (2U) and 10cm×10cm×30cm (3U) in size. Advantageously, they can be launched from standardised ejection modules such as the Poly-Picosatellite Orbital Deployer (P-POD) [1]. To date, several CubeSats have been designed, launched and operated successfully at low Earth orbit; examples include CanX-1, CUTE-1, and AUU; see [2]. As CubeSats are small, there is a limit on their weight, volume and power supply. Consequently, CubeSats are only limited to simple earth observation or space exploration missions. For example, the Firefly CubeSat mission developed by NASA aims to explore the relationship between lightning and Terrestrial Gamma-ray Flashes (TGFs) in space. Currently, the data collected from Firefly shows up to 50 times lightening strikes daily; this, however, is not sufficient to answer the mystery of TGFs. According to NASA's investigator Doug Rowland, CubeSats need a higher data rate and even longer mission durations [3].

One way to extend the capabilities of CubeSats is to have a swarm of CubeSats; each swarm is envisaged to have tens to hundreds of cooperating CubeSats. The aim is to share and distribute power, memory and bandwidth. The resulting cooperative CubeSat network is thus envisaged to have a high degree of functionalities than conventional satellites. Indeed, CubeSats swarms could significantly improve transmission capacity and mission lifetimes. A subset of CubeSats can form a virtual antenna array to realise a larger aperture area with higher reliability. An example of CubeSat swarm is realized in the QB50 project [4]; a collaboration among 50 different partners from all over the world.

A swarm of CubeSats requires reliable and efficient inter-CubeSat communication links. Specifically, high-speed inter-satellite links will help to facilitate formation-flying missions where CubeSats maintain the desired relative separations, positions and orientations. One solution is to employ omni-directional antennas. However, they are not suitable because they have a relatively low gain, and thus, they only provide short distance communication and low data rates. Another issue is their high power requirement, which is a challenge as CubeSats have limited power supply. To date, most CubeSat missions have employed simple antenna designs like wire and patch antennas. In most cases, a wire antenna needs deployment after a CubeSat is launched into space. Deployment usually involves a composite tape spring [5, 6]. Wire antennas usually operate at lower frequencies (lower than S-Band) and have a wide length. For example, reference [6] outlines a deployable dipole antenna using curved bi-stable composite tape-spring. The dipole antenna operates at 250 MHz, and its total length is 22 inch (around five times larger than a CubeSat edge) which is equal to 0.465λ. Consequently, it is not suitable to employ a long wire antenna on CubeSats because they may introduce positioning problems when the spacing between CubeSats is narrow. Given the aforementioned problems, patch antennas are good alternatives as they have a low profile, do not require a deployment solution, easy to realize, are relatively low in cost and have small dimensions [7]. Hence, several S-band planar antennas have been proposed for CubeSats [8-10]. However, increasing antenna gain directionally can provide more flexibility for CubeSats communicating as part of a swarm. On the other hand, single element antennas are limited in that the maximum gain in a particular direction is restricted by their dimensions. This has implication on the attainable data rate. Another problem is that any adjustments to their radiation patterns or directions entail re-orienting a CubeSat.

An antenna array could solve the forementioned issues. Specifically, in a swarm, antennas that are capable of electronic directivity are desirable. The resulting array can compensate for gain variations and reduce the impact of satellite orientation errors[11]. In particular, an antenna array has the following advantages. Firstly, it has a relatively high gain as compared to single element antennas and has better trade-off between antenna size and performance. Secondly, an antenna array enables an electronically steerable beam. This makes satellites more versatile. Indeed, instead of physically re-orienting a CubeSat to establish a link, its beam can be steered by controlling the excitation phase of each element. Thirdly, it is more flexible in terms of system maintenance and recovery. This is because additional elements can be added when the mission needs a larger aperture, and the failure of a single element may not significantly impact on overall system performance.

To date, a few works have proposed to equip an antenna array on CubeSats. Reference [10] has proposed a swarm to earth communication system for a swarm of 50 nano-satellites that equipped with low-frequency antennas. A planar phased antenna array for Inter-CubeSat communications that can enable beam scanning was proposed by [12]. The antenna's beam can be steered within a semi-angle of 40 degrees. A technique that helps to achieve circular polarization for an antenna array was also proposed by [13]. This designed array is shown in Fig.1. The array consists of several sub-arrays. Each subarray contains four patches and has a size of 30mm×30mm. At a frequency of 5.8GHz, the sub-array has a gain of 5.1dB while the complete array achieves a gain around 5.8dB. This planar phased array is placed on one of the 1U CubeSat surface, and all of its sub-arrays share the same substrate plane and are designed under the same frequency. Using dipole antennas to form an array is likely to improve the total gain, increase directivity and bandwidth. A log-periodic crossed dipole array is proposed in [14]. It achieves a directional high gain but with less flexibility of structure. Each dipole element should be crossed with one another. And the differences between the lengths of each pair of dipole must be a logarithm function. In addition, inflatable antenna is another candidate to contribute to antenna array for CubeSat. It has received much attention recently. It has a high gain and good directivity, making them feasible for space missions. The Jet Propulsion Laboratory (JPL) has designed an inflatable antenna in combination with an inflatable antenna array [15]. The antenna is a parabolic dish reflector made from metalized mylar on one side and clear mylar on the other, and fed by a patch antenna. When the patch antenna radiates from the inflated inside volume to a parabolic metalized mylar surface, the radio signal will be reflected to pass through the clear mylar and reach the receiver. The simulation results on a single inflatable antenna show a high 23dB gain could be achieved at S-band with an 8dB patch antenna, and its radiation pattern shows good directivity. They also make comparison based on estimated antenna gains and show higher Equivalent Isotropically Radiated Power (EIRP) values can be achieved with an array with 2, 4, 8, 16 elements, compared with a single element [16]. It is ideal that each CubeSat in a swarm carrying an inflatable antenna to form a virtual antenna array. The antenna system on each satellite can only be adjusted based on the characteristic of single inflatable element.

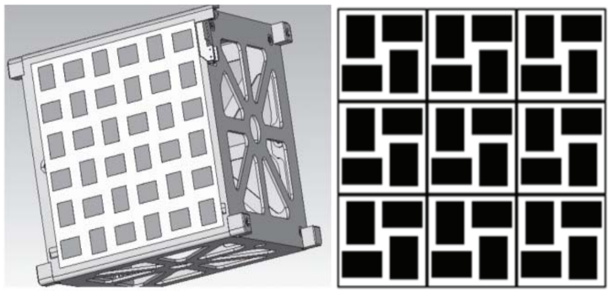

Fig.1. Planar antenna array on a CubeSat surface [12]

In this paper, we aim to develop CubeSat antenna solutions that take advantages of an antenna array and obtain a high gain directional performance. We proposed a 3x1 dipole array and a cluster of three 3x1 dipole arrays, both of which are printed on board. They have the same advantages as a patch antenna with regards to shape and dimension, but are more flexible than a patch antenna in terms of steerable directivity and adjustment to single-element failure. They can be perfectly attached within one of the CubeSat surfaces to avoid deployment. The cluster of three 3x1 dipole arrays combines three printed arrays sharing the same corner on a CubeSat. The simulation results show the designed array cluster could achieve a high gain of 5.03dB and good directivity for CubeSat communications in the S-band. It has potential to be tested under various frequencies among each sub-arrays. And it is possible to enable the steerability of the overall radiation beam through changing the phase weights of single dipole elements in each sub-array.

II. ANTENNA ARRAYS

Normally, single element antennas have relatively wide radiation patterns with low gain and directivity.

When designing an antenna array, antenna elements are combined and work cooperatively from their excitation signals with specific amplitude and phase relationship. As a result of the combination of radiation from each element, the array could act as a single antenna with improved overall gain, signal to noise ratio (SNR) and reception diversity. In order to achieve a good directivity, it is required that the radiation field from each element of the array add up in the desired direction but cancel each other in other directions [17]. An antenna array enables signal processing for the combination of separate antenna output. Some basic arraying techniques applying signal processing schemes and their applications in deep space are introduced in [18].

Individual antenna elements can be positioned linearly forming a linear array or along rectangular grid to form MxN planar arrays. Compared with linear arrays, planar arrays can provide more flexibility in terms of controlling the shape of the array patterns and achieving lower side lobes. They can also enable the scan of the main beam across the entire space.

Consider an MxN rectangular array on x-y surface with N elements on x-axis and M elements on y-axis. The distance between each element on x-axis is d_x while the distance between each element on y-axis is d_y.

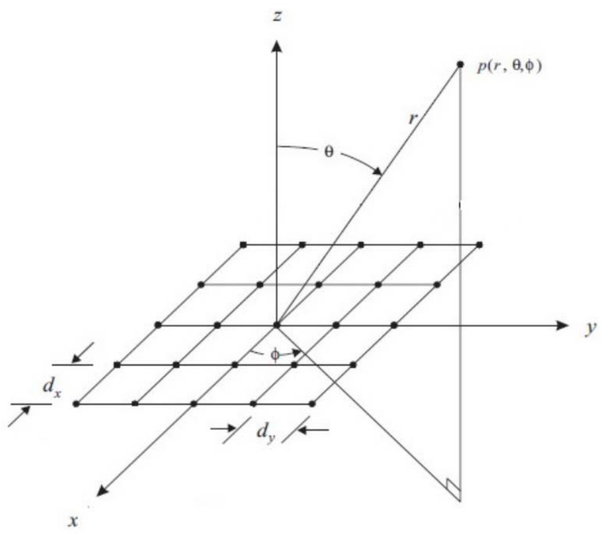

Fig.2. Planar array [17]

According to [17], the array factor of the MxN planar array could be calculated as follows:

$$AF = AF_x \times AF_y = \sum_{n=1}^{N} e^{-j(n-1)(kd_x sin\theta cos\varphi+\beta_x)}$$

$$\times \sum_{m=1}^{M} e^{-j(n-1)(kd_y sin\theta sin\varphi+\beta_y)} \qquad (1)$$

Where $\beta_x = -kd_x sin\theta_0 cos\varphi_0$, $\beta_y = -kd_y sin\theta_0 sin\varphi_0$ represent the phase excitation and $k = 2\pi/\lambda$is the propagation constant.

Theoretically, the spacing between each element d_x and d_y should be less than $\lambda/2$, otherwise, besides main lobes, some grating lobes will appear. The position of the main beam could be changed through adjusting the value of β_x and β_y.

III. Design of a 3x1 Dipole Array on CubeSat

In this section, a single 3x1dipole array is designed and tested on one face of the satellite by High Frequency Structure Simulator (HFSS) [19], as shown in Fig.3.

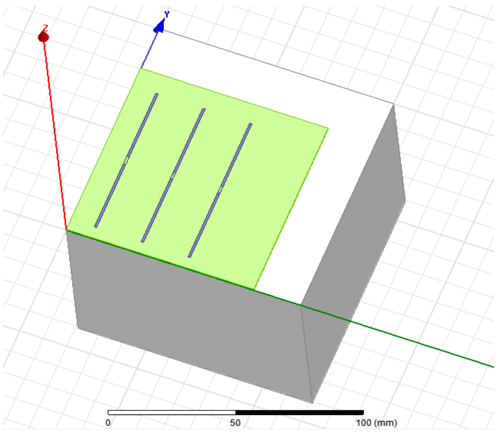

Fig.3. Model of 3x1 dipole arrays on CubeSat

The length of each dipole element printed on board is 62.5mm while the width is 1mm. Each element of the array is parallel with the other. The spacing between each single dipole is 22mm, and the size of the ground plane is 80mm×80mm. The simulation results in Fig.4 and Fig.5 show that the maximum gain value is 8.3dB and the main beam is pointing to the direction of z-axis. The antenna array achieves a small return loss of -27.35dB at a frequency of 2.5GHz and a bandwidth of 120MHz.

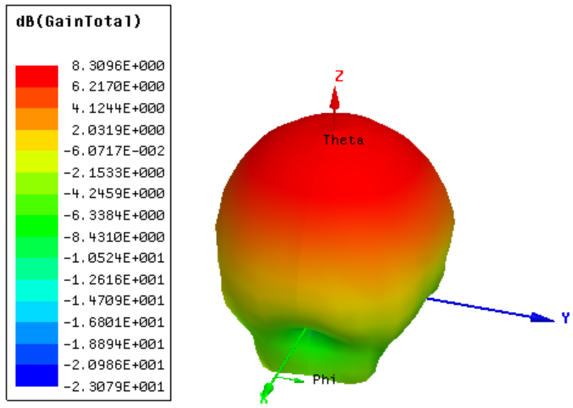

Fig.4. 3D polar plot of 3x1 dipole array on CubeSat

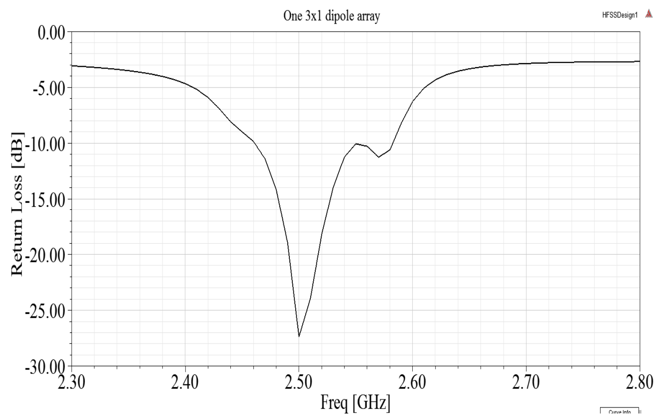

Fig.5. Return loss of 3x1 dipole array

IV. Dipole Array Cluster on CubeSat

By only placing the array on one face, communication directivity is limited especially for inter CubeSat connectivity. In this section we propose distributing the array on three faces of the CubeSat, with each corner occupying a 3x1 dipole array. The array cluster includes three sub-arrays; each sub-array is a printed 3x1 dipole antenna similar to the design in section III. Three boards are attached on three surfaces of CubeSat and sharing the same corner as shown in Fig.6.

Fig.7 and Fig.8 show the simulation results of this designed model. With matched impedance set as a common value of 50Ω, running the simulation with sweeping frequency range from 2.2GHz to 2.8GHz, a high gain of 5.03 dB are achieved. The direction of the main beam is almost perpendicular along the x-z surface. The return loss of this array cluster is -21.85dB at 2.56GHz, while the bandwidth is narrow at 64MHz. Compared with the single 3x1 dipole array design in section III, using three sub-arrays sharing one corner of the cube can lead to a lower gain value and less bandwidth.

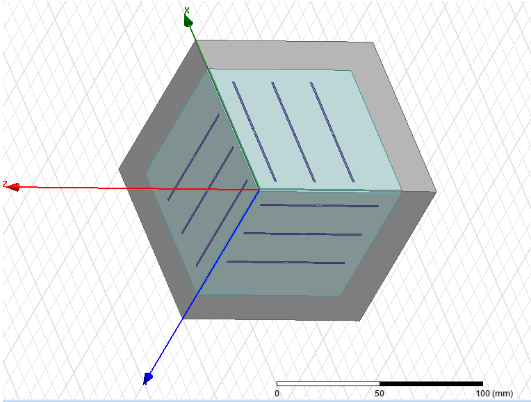

Fig.6. Model of three 3x1 dipole arrays on CubeSat

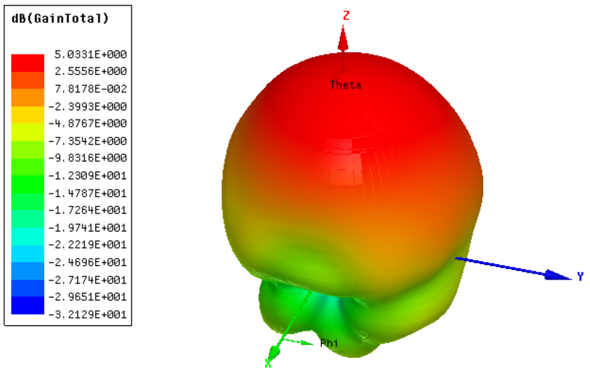

Fig.7. 3D polar plot of three 3x1 dipole arrays on CubeSat

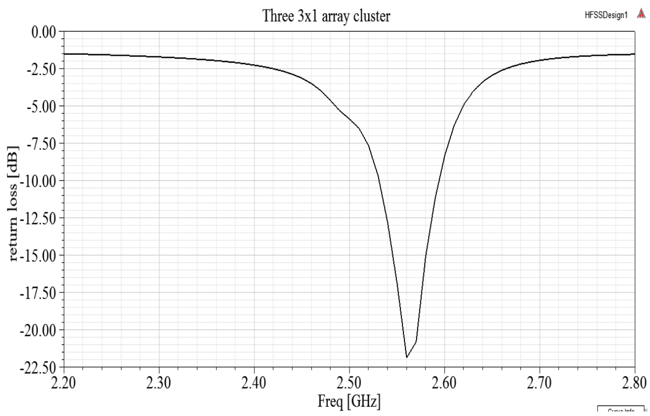

Fig.8. Return loss of three 3x1 dipole array on CubeSat

V. CONCLUSION

In this paper, a cluster of printed 3x1 dipole antennas that can be attached on the corner of one of the CubeSat surfaces are proposed and simulated. In addition, we showed simulated results for the case of three 3x1 dipole arrays installed on three different CubeSat surfaces but sharing the same corner. The simulation results shows high gain value for single 3x1 array and three 3x1 array, respectively as 8.3dB and 5.03dB. These two cases of 3x1 arrays make the main beam radiate maximum power along z-axis. But the bandwidths are not large at only 120MHz for single 3x1 array and 64MHz for three 3x1 array cluster.

REFERENCE

[1] J. Puig-Suari, C. Turner, and W. Ahlgren, "Development of the standard CubeSat deployer and a CubeSat class PicoSatellite," in *Aerospace Conference, 2001, IEEE Proceedings.*, 2001, pp. 1/347-1/353 vol. 1.

[2] B. Klofas, J. Anderson, and K. Leveque, "A survey of cubesat communication systems," in *5th Annual CubeSat Developers' Workshop*, 2008.

[3] "NASA " *[Online] available http://www.nasa.gov/.*

[4] "An international network of 50 CubeSats Project " *[online] available: http://www.qb50.eu/, accessed Oct.24,2015.*

[5] J. Otterstad, "Antenna System for NCUBE," 2003.

[6] T. Murphey, S. Jeon, A. Biskner, and G. Sanford, "Deployable booms and antennas using bi-stable tape-springs," 2010.

[7] F. Em. Tubbal, R. Raad, and K.-W. Chin, "A survey and study of planar antennas for pico-satellites," *IEEE Access,* vol. 3, pp. 2590-2612, 2015.

[8] A. Nascetti, E. Pittella, P. Teofilatto, and S. Pisa, "High-Gain S-band Patch Antenna System for Earth-Observation CubeSat Satellites," *IEEE Antennas and Wireless Propagation Letters,* vol. 14, pp. 434-437, 2015.

[9] F. Em. Tubbal, R. Raad, K.-W. Chin, and B. Butters, "S-band Planar Antennas for a CubeSat," *International Journal on Electrical Engineering & Informatics,* vol. 7, pp. 559-568, 2015.

[10] N. G. Orr, J. K. Eyer, B. P. Larouche, and R. E. Zee, "Precision formation flight: The CanX-4 and CanX-5 dual nanosatellite mission," in *European Space Agency, (Special Publication) ESA SP*, 2008.

[11] A. Budianu, A. Meijerink, and M. J. Bentum, "Swarm-to-Earth communication in OLFAR," *Acta Astronautica,* vol. 107, pp. 14-19, 2015.

[12] R. M. Rodrguez-Osorio and E. F. Ramrez, "A Hands-On Education Project: Antenna Design for Inter-CubeSat Communications [Education Column]," *IEEE Antennas and Propagation Magazine,* vol. 54, pp. 211-224, 2012.

[13] J. Huang, "A technique for an array to generate circular polarization with linearly polarized elements," *IEEE Transactions on Antennas and Propagation,* vol. 34, pp. 1113-1124, 1986.

[14] J. Costantine, Y. Tawk, A. Ernest, and C. G. Christodoulou, "Deployable antennas for CubeSat and space communications," in *2012 6th European Conference on Antennas and Propagation (EUCAP)*, 2012, pp. 837-840.

[15] A. Babuscia, B. Corbin, M. Knapp, R. Jensen-Clem, M. Van de Loo, and S. Seager, "Inflatable antenna for cubesats: Motivation for development and antenna design," *Acta Astronautica,* vol. 91, pp. 322-332, 2013.

[16] A. Babuscia, T. Choi, C. Lee, and K. M. Cheung, "Inflatable antennas and arrays for interplanetary communication using CubeSats and smallsats," in *IEEE Aerospace Conference Proceedings*, 2015.

[17] C. A. Balanis, *Antenna theory : analysis and design / Constantine A. Balanis*: Hoboken, NJ : John Wiley, 2005., 2005.

[18] D. H. Rogstad, A. Mileant, and T. T. Pham, *Antenna arraying techniques in the deep space network* vol. 6: John Wiley & Sons, 2005.

[19] "High Frequency Struture Simulator " *[online] available* http://www.ansys.com/.