DIELECTRIC RESONATOR REFLECTARRAY ANTENNA IN KU-BAND

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Specially dedicated to muslim brothers and sisters around the world, may be benefits to the community.

For family, lectures and friends,

thanks for support, teach, guide and pray for me.

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ABSTRACT

Direct broadcasting satellite has become a vital system in satellite communication globally especially for digital broadcasting purposes. Currently, a parabolic antenna is normally used for this application, however the advantages of reflectarray which is flat in shape and possibility for beam steering capability make the reflectarray antenna is one of the interesting topic to be studied. At the current time, many reflectarrays are based on microstrip technology. Nevertheless, at high frequency the conductor loss is high and the antenna efficiency will be reduced. An interesting solution is to use dielectric resonator antennas (DRAs) as the reflectarray elements. In facts, DRA can give low loss and high bandwidth. In this thesis, firstly four different slots with alphabets underneath the rectangular DRA have been investigated as unit-cell for reflectarray. A new structure of rectangular DRA with C-shaped slot unit-cell has been proposed which can give high phase range (321.9^{o}) and low loss (0.3685^{o}). This structure is then being validated experimentally in Ku-Band. Next, the mutual coupling effects between unit-cell in the reflectarray are studied and a simulation technique based on Finite Different Time Domain (FDTD) is proposed. By doing so, this simulation technique is most suitable to predict the actual reflectarray radiation pattern. Finally, the reflectarray antenna composed of 24 x 24 unit-cells based on DRA with C-shaped slot is proposed at 12 GHz.

ABSTRAK

Penyiaran satelit langsung telah menjadi satu sistem yang penting dalam komunikasi satelit global terutamanya untuk tujuan penyiaran digital. Pada masa ini, penggunaannya menggunakan antena parabola, namun kelebihan *reflectarray* dalam bentuk yang rata dan kemungkinan untuk keupayaan stereng rasuk membuat antena *reflectarray* adalah salah satu topik yang menarik untuk dikaji. Pada masa kini, banyak *reflectarray* adalah berdasarkan kepada teknologi mikrostrip. Walau bagaimanapun, pada frekuensi tinggi, kehilangan konduktor adalah tinggi dan kecekapan antena akan dikurangkan. Satu penyelesaian yang menarik adalah dengan menggunakan antena resonator dielektrik (DRA) sebagai elemen reflectarray. Malahan, DRA boleh memberi kerugian yang rendah dan jalur lebar yang tinggi. Dalam tesis ini, untuk langkah awal, empat lubang yang berbeza dengan bentuk huruf direka bentuk di bawah DRA segi empat tepat telah disiasat sebagai unit-sel untuk *reflectarray*. Satu struktur baru DRA segi empat tepat dengan berbentuk lubang-C unit-sel telah dicadangkan, di mana ia boleh memberi pelbagai fasa yang tinggi (321.9^{o}) dan kerugian yang rendah (0.3685^{o}). Struktur ini kemudiannya yang disahkan secara eksperimen di *Ku-Band*. Seterusnya, kesan gandingan bersama antara unit-sel dalam *reflectarray* dikaji dan teknik simulasi berdasarkan *Finite Different Time Domain* (FDTD) dicadangkan. Dengan berbuat demikian, teknik simulasi ini adalah yang paling sesuai digunakan untuk meramal corak sinaran reflectarray sebenar. Akhir sekali, antena *reflectarray* yang terdiri daripada 24 x 24 unit-sel berdasarkan DRA dengan berbentuk lubang-C adalah dicadangkan pada 12 GHz.

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LIST OF ABBREVIATION

cm	-	Centimeter
CST MWS	-	Computer Simulation Technology Microwave Studio
dB	-	Decibel
dBi	-	Decibels with respect to isotropic
DBS	-	Direct Boardcast Satellite
DRA	-	Dielectric Resonator Antenna
E-plane	-	Electric Plane
FDTD	-	Finite Different Time Domain
FR-4	-	Flame Retardant-4
GHz	-	Gigahertz
H-Plane	-	Magnetizing Field
MATLAB	-	Matrix Laboratory
mm	-	Milimeter
PEC	-	Perfect Electric Conductor
PMC	-	Perfect Magnetic Conductor
PTFE	-	Polytetrafluoroethylene
RT-Duroid	-	Rogers
TE	-	Transverse Electromagnetic
TM	-	Transverse Magnetic
TEM	-	Transverse Electromagnetic Mode
VNA	-	Vector Network Analyser
WR	-	Waveguide Rectangular
WGS	-	Waveguide simulator

LIST OF SYMBOLS

^{o}	-	Degree
$\vec{\varepsilon}$	-	Disturbance factor
s	-	Distance between the microstripline and DRA
$\vec{E}$	-	Electric field
f	-	Frequency
S	-	Incident wave
L_s	-	Length of the slot
Ω	-	Ohm
ε_r	-	Permittivity
Φ	-	Phase
π	-	Phi
f_o	-	resonant frequency
C	-	Speed of light
S_{11}	-	S-parameter from port one for a signal incident on port one
θ	-	Theta
$\vec{n}$	-	Unit vector normal
λ	-	Wavelength
k_0	-	wave number
kx, ky, kz	-	wavenumber along x, y and z directions

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In the era of information technology, the utilization of satellite communication that is designed originally for sending telephone, radio, television and other signals across the country and around the world has become more popular recently. Nowadays, the major source of revenue for satellite communication industry is the television satellite broadcasting. Television satellite is able to deliver a few signals of large bandwidth to many receivers and becomes a more precise match for the capabilities of geosynchronous communication satellite. One of the technology that is used for Direct-To-Home satellite television service is Direct Broadcast Satellite (DBS).

As the name implies, DBS is a system that distributes television signals by broadcasting directly from satellite to end-user. The ability of DBS is to deliver hundreds of television channels and confidential information to millions of people around the world without being connected to the wires.

In order to receive DBS, subscriber antennas should possess high gain characteristic [1]. Conventionally, in order to have high gain characteristic antennas, most of the antennas often used parabolic reflector, which is generally bulky in size and large in mass. As a solution, reflectarray antenna has been developed extensively to accomplish the requirement of the mission of DBS. This new type of antenna was presented in the early 1960s [2]. Reflectarray antenna is the suitable choice for space applications such as earth remote sensing and space exploration [3]. It is because this type of antenna is able to reradiate and scatter the incident field with electrical phases that is required to form a planar phase front in the far-field distance [4]. In addition, reflectarray antenna can be designed to fulfill all the typical requirements of a transmitted and received DBS antenna that provides the electrical requirements [5]. The reflectarray antenna design for DBS has been presented in literature [5, 6].

There are a lot of advantages using reflectarray antenna. One of the advantages is the ability to achieve very good efficiency for a large aperture. However, the use of metal waveguides in the reflectarray antenna leads to a large and bulky structure, and the antenna is mostly languished in the literature for many years [7].

Figure 1.1: Photo of parabolic reflect array for space applications [4].

Basically, reflectarray antenna is a combination of the features of phased array antenna and reflector antenna. Then in the early 1960s, the first concept of reflectarray antenna was introduced in the waveguide reflectarray. The capability of achieving co-phasal reradiated far-field beams has been demonstrated. However, the antenna is still bulky and heavy because it operates at relatively low microwave frequencies.

As time goes on, in the late 1980s and early 1990s, printed (microstrip) antenna was developed [8]. With advantages such easy deployment in space, reducing cost production, low weight, flatness and flexible electrical performance in terms of feeding, polarization control, beam steering, amplification and multiple beam capability, a lot of researchers have contributed to this field. Nevertheless, for microstrip reflectarray at millimeter-waves, the efficiency of the antenna may be reduced significantly and the conductor loss becomes severe. Based on all these facts, the author has been motivated to propose a new design of reflectarray antenna.

The new reflectarray antenna design consists of dielectric resonator antenna (DRA) unit-cell loaded with alphabet shape slot. Due to the interesting features of DRA such as low loss, broad bandwidth small mutual coupling effect and higher radiation efficiency, thus DRA has become the main subject of the study. Meanwhile, in order to excites the magnetic fields in the DRA [9], alphabet shape slot is loaded as the main frequency tunable for the DRA. Alphabet shape slot is chosen due to the various geometries.

1.2 Problem Statement

Most long distance wireless communication such as DBS requires high gain antenna operation. Conventionally, it has to rely on the parabolic reflector antenna. However, most of the structure of parabolic reflectors caused the antenna difficult to be implemented, especially at higher microwave. This is due to the specific parabolic curve [4]. Designing the reflector antenna in a specific parabolic antenna has led to the antenna being slow and has narrow angle beam scanning. Furthermore, the large number of amplifiers and complicated beamformer are needed in the feed network, which makes the phased array antenna becomes very expensive. As an alternative, reflectarray antenna has been proposed in this thesis, which is much simpler and has reliable folding mechanism due to the flat structure [4].

The features of reflectarray antenna have shown that the viability of this technology are able to transmit and received space antenna for telecommunications and broadcasting [5]. Recently, many investigation of reflectarray antenna are based on microstrip design [8, 10, 11]. The unit-cell of microstrip reflectarray will be controlled to provide higher efficiency for very large aperture. It can also has its main beam designed to tilt at a large angle from its broadside direction. Nevertheless, at high frequencies, the conductor loss of microstrip reflectarray becomes severe [12]. In addition, the mutual coupling effect of microstrip element that printed on the substrate becomes noteworthy [13]. Due to this drawback, this thesis proposes a new reflectarray antenna based on DRA. DRA is an interesting element that can provide low loss and high bandwidth compared to microstrip antenna.

In order to design the overall antenna, the reflectarray environment from the non-identical unit-cells is considered. This is due to the different phase shift at each unit-cell. Unfortunately, most of the approach in the unit-cell analysis has been carried out for the single unit-cell [11, 14] which assumes that all unit-cell in the array is identical which is not true in reality. Therefore, the mutual coupling effects between the unit-cell in the reflectarray antenna are studied.

1.3 Objectives of the Research

The objectives of this research are:

1) To design, fabricate and test a new unit-cell based on DRA that can give high phase range approximate to 360˚ or more.
2) To design a reflectarray antenna that is based on DRA.
3) To investigate a new simulation technique based on Finite Different Time Domain (FDTD) that can analyse mutual coupling effect and predict the overall radiation pattern of reflectarray.

1.4 Scopes of the Research

In order to fulfill the objectives of the study, this project involves with designing a new unit-cell based on a rectangular DRA as the reflectarray element. A slot has been loaded underneath the unit-cell that acts as the tuning parameter to control the phase of the reflection coefficient. Four different alphabet shape slots have been investigated in order to have a large phase range. The large achievable phase range and low loss (insertion loss less than 1 dB) will be the main goal to design a better performance of the reflectarray element. The unit-cell will be designed at 12 GHz for DBS. The design is simulated using commercial CST software. Meanwhile, the fabrication and measurement have been carried out using WR 90 waveguide.

This thesis also studies the disturbance phenomena inside the structure, which is called mutual coupling effect. The simulation technique to analyse the mutual coupling effect in reflectarray environment is based on FDTD, which includes the coupling effect from the actual neighbouring unit-cell. A new method based on FDTD is introduced to predict the radiation pattern of the overall DRA reflectarray.

Finally, the whole reflectarray antenna with 24 x 24 elements is designed and simulated. This DRA reflectarray is designed at broadside radiation.

1.5 Organization of the Thesis

Basically, in this thesis, the flow of the whole project is present in Figure 1.2 below:

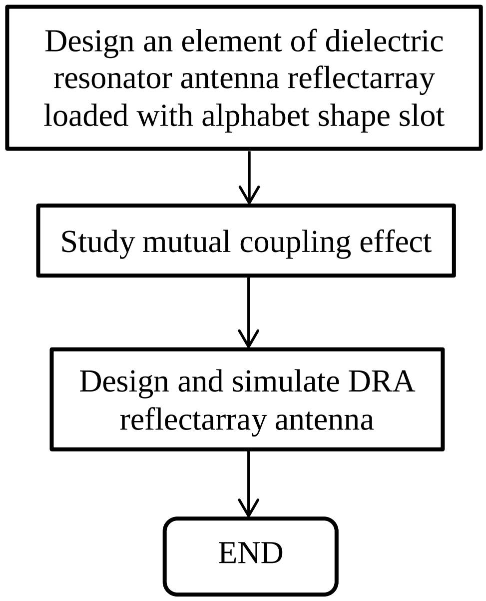

Figure 1.2: Flow chart of whole project

This thesis is organized into four main chapters and one final chapter for the conclusion. The flow of each chapter is briefly described in the following paragraphs.

Chapter 1 presents the general introduction of this research. This includes the background study of the reflectarray antenna and the problem occurs in the development of reflectarray element that gives the motivation for further study this research. In addition, the objectives need to be achieved and the scopes of the research have been determined in order to design the new unit-cell of the reflectarray antenna.

Chapter 2 presents a basic literature review that is related to the design. This gives an overview about the history of the development of the reflectarray antenna since its invention. The development has shown that the reflectarray antenna becomes popular in the current research field. This includes the usage of printed microstrip reflectarray antenna that has been produced in various forms to achieve the best performance in designing reflectarray antenna. This chapter also explains the concept, most significant features, advantages and disadvantages of the reflectarray element followed by the DRA that will be used to design as a new unit-cell reflectarray antenna.

The third chapter focuses on designing the new unit-cell in the simulation and fabrication process. The steps taken have been discussed, including the determination of size of DRA, the waveguide port setting, defining the boundary condition and the inter-element spacing. In order to have a better performance in designing the reflectarray antenna, four different alphabet shape slots have been investigated and discussed in this chapter. In the end, the best unit-cell is selected as the reflectarray element. In addition, a 'full substrate' has been introduced to investigate the operating principle of the proposed unit-cell.

The fourth chapter discusses about the mutual coupling effects in the reflectarray environment. It is found that the nearest neighbouring unit-cell in E-plane has a large mutual coupling effect compared to the neighbouring unit-cell located at H-plane. A simulation technique based on FDTD has been proposed to predict the overall radiation pattern of the reflectarray. A reflectarray prototype that operates at 30 GHz [15] has been chosen as the benchmark. A good agreement between simulation and measurement results has been discussed in this chapter.

The fifth chapter discusses the overall design of DRA reflectarray antenna. This also includes the horn antenna design and the procedure to define the dimensions of each unit-cell of the DRA reflectarray. The overall conclusion is given in the last section of the thesis.

REFERENCES

[1]. Huang, J. *Microstrip Reflectarray*. in *Antennas and Propagation Society International Symposium, 1991. AP-S. Digest*. 1991.

[2] Berry, *D. G.,* Malech, R. G. and Kennedy,W. A. *The Reflectarray Antenna,* in *IEEE Trans Antenna Porpagate AP-11*. 1963. p. 645-651.

[3] Inam, M., et al. *Analysis of Reflectarrays Printed Above Variable Substrate Thicknesses*. in *Applied Electromagnetics (APACE), 2010 IEEE Asia-Pacific Conference on*. 2010.

[4] Huang, J. and Encinar, J. A. *Reflectarray Antennas*. 2007: A John Wiley & Sons, Inc., Publication.

[5] Encinar, J. A., et al., *A Transmit-Receive Reflectarray Antenna for Direct Broadcast Satellite Applications.* Antennas and Propagation, IEEE Transactions on, 2011. **59**(9): p. 3255-3264.

[6] Zornoza, J. A. and Encinar, J. A., *Design Of Shaped Beam Reflectarrays for Direct Broadcast Satellites*, in *JINA, Antennas International symposium, Antennas*. 2002.

[7] Weile, D. S. *Reviews and abstracts of reflectarray antenna*, in *IEEE Antennas and Propagation Reviews and Abstract of Reflectarray Antenna Magazine*. 2008.

[8] Huang, J. *Microstrip Reflectarray Antenna for the SCANSCAT Radar Application.* JPL Publication 1990. **1**.

[9] Volakis, J. L., Johnson, R. C. and Jasik, H. *Antenna Engineering Handbook*. 2007, Exeter, DEV, United Kingdom: McGraw-Hill.

[10] Zubir, F., et al., *Design and Analysis of Microstrip Reflectarray Antenna with Minkowski Shape Radiating Element.* Progress In Electromagnetics Research B, 2010. **24**: p. 317–331.

[11] Veneri, F., G. Angiulli, and G. Di Massa, *Design of microstrip reflectarray using data from isolated patch analysis.* Microw. Opt. Technol, 2002. **34**(6): p. 411–413.

[12] Jamaluddin, M. H., et al., *Reflectarray element based on strip-loaded dielectric resonator antenna.* Electronics Letters, 2008. **44**(11): p. 664.

[13] Abd-Elhady, M. A., et al., *Dual Sized Varying Slot Lengths Loading Dielectric Resonator Reflectarray.* International Journal of Electromagnetics and Applications, 2012. **2**(3): p. 46-50.

[14] Targonski, S. D. and Pozar, D. M. *Analysis and Design of a Microstrip reflectarray using patches of variable size*. in *Antennas and Propagation Society International* Pozar *Symposium, 1994. AP-S. Digest*. 1994.

[15] Jamaluddin, M. H., Sauleau, R., Castel, X., Benzerga R. and Le Coq, L. *Design, Fabrication and Characterization of a Dielectric Resonator Antenna Reflectarray in Ka-Band.* Progress In Electromagnetics Research B, 2010. **25**(July): p. 261-275.

[16] Jamaluddin, M. H., *Dielectric resonator antenna reflectarrays – Design and characterization in Ka-band*, in *Institut d'Electronique et de Télécommunications de Rennes*. 2010, Universite De Rennes 1.

[17] Rajagopalan, H. and Rahmat-Samii, Y. *Reflectarray antennas: An intuitive explanation of reflection phase behavior*. in *General Assembly and Scientific Symposium, 2011 XXXth URSI*. 2011.

[18] Huang, J., *Bandwidth Study of Microstrip Reflectarray And A Novel Phased Reflectarray Concept*, in *Antennas and Propagation Society International Symposium, 1995. AP-S. Digest* 1995. p. 582-585.

[19] Rengarajan, S. R. *Reflectarrays of Rectangular Microstrip Patches for Dual-Polarization Dual-Beam Radar Interferometers.* Progress In Electromagnetics Research, 2013. **133**: p. 1-15.

[20] Srikanth, M., Raghavan, S. and Rao, P.H. *Design and Development of Folded Stub Loaded Microstrip Reflectarray Antenna*. in *Applied Electromagnetics Conference (AEMC), 2011 IEEE*. 2011.

[21] Ismail, M.Y., et al. *Slotted tunable reflectarray antenna*. in *Microwave Conference Proceedings (APMC), 2011 Asia-Pacific*. 2011.

[22] Javor, R.D., Xiao-Dong, W. and Kai, C. *Design and Performance of a Microstrip Reflectarray Antenna.* Antennas and Propagation, IEEE Transactions on, 1995. **43**(9): p. 932-939.

[23] Chaharmir, M. R., et al., *Reflectarray with Variable Slots on Ground Plane.* IEE Proceedings - Microwaves, Antennas and Propagation, 2003. **150**(6): p. 436.

[24] Cadoret, D., et al., *Design and Measurement of New Reflectarray Antenna Using Microstrip Patches Loaded with Slot.* Electronics Letters, 2005. **41**(11): p. 623-624.

[25] Cadoret, D., et al. *A Dual Linear Polarized Printed Reflectarray using Slot Loaded Patch Elements*. in *Antennas and Propagation, 2007. EuCAP 2007. The Second European Conference on*. 2007.

[26] Ahmadi, F., et al., *Dual Linear-Polarized Dielectric Resonator Reflectarray Antenna.* Antennas and Wireless Propagation Letters, IEEE, 2013. **12**: p. 635-638.

[27] Chang, T. N. and Chung, C.H. *Two-layer Variable Slot Length Reflectarray*, in *Progress In Electromagnetics Research Symposium,*. 2008.

[28] Abd-Elhady, M., et al., *Varying Slot Lengths Strip Loading Squared Dielectric Resonator Reflectarray.* International Journal of Electromagnetics and Applications, 2012. **2**(3): p. 51-55.

[29] Gopakumar, C., *Development and Analysis of a Novel Isosceles Trapezoidal Dielectric Resonator Antenna for Wireless Communication*, in *Department of Electronics*. 2011, Cochin University of Science and Technology: INDIA.

[30] Khan, U. M. and Milutinovic, M. *Dual Polarized Dielectric Resonator Antenna*, in *Department of Computer Science and Engineering*. 2010, Chalmers University of Technology: Göteborg, Sweden. p. 113.

[31] Long, S. A., McAllister, M. and Liang, S. *The resonant Cylindrical Dielectric Cavity Antenna.* Antennas and Propagation, IEEE Transactions on, 1983. **31**(3): p. 406-412.

[32] Buerkle, A., Sarabandi, K. and Mosallaei, H. *Compact Slot and Dielectric Resonator Antenna with Dual-Resonance, Broadband Characteristics.* Antennas and Propagation, IEEE Transactions on, 2005. **53**(3): p. 1020-1027.

[33] Makwana, G. D. and Vinoy, K. J. *Design of a Compact Rectangular Dielectric Resonator Antenna at 2.4GHz.* Progress In Electromagnetics Research C, 2009. **11**: p. 69-79.

[34] Madhuri, R. G., Hadalgi, P. M. and Mallikarjun, S. L. *U-Slot Rectangular Dielectric Resonator Antenna for Wideband Applications.* International Journal of Electronics Engineering, , 2010. **2**: p. 249 – 252.

[35] Al-Zoubi, A. S., Kishk, A. A. and Glisson, A. W. *Analysis and Design of a Rectangular Dielectric Resonator Antenna Fed By Dielectric Image Line Through Narrow Slots.* Progress In Electromagnetics Research C, 2007. **77**: p. 379-390.

[36] Neshati, M. H. and Wu, Z. *Microstrip Slot Coupled Rectangular Dielectric Resonator Antenna, Theoretical Modelling & Experiment.*, in *Antennas and Propagation, 2003. (ICAP 2003). Twelfth International Conference on (Conf. Publ. No. 491)* 2003. p. 759- 762.

[37] Denidni, T. A., Rao, Q. and Sebak, A. R. *Two-ring Slot-fed Dielectric Resonator Antenna for Dual-Frequency Operation.* Microwave and Optical Technology Letters, 2005. **44**(5): p. 448-451.

[38] Kwok-Wa, L. and Hoi Kuen, N. *The Slot-Coupled Hemispherical Dielectric Resonator Antenna with a Parasitic Patch: Applications to The Circularly Polarized Antenna and Wide-Band Antenna.* Antennas and Propagation, IEEE Transactions on, 2005. **53**(5): p. 1762-1769.

[39] Raggad, H., et al. *Cylindrical Dielectric Resonator Antenna Fed by A Stair Slot In The Ground Plane of A Microstripline*. in *General Assembly and Scientific Symposium, 2011 XXXth URSI*. 2011: p . 1-4.

[40] Khalily, M., et al., *Wideband P-Shaped Dielectric Resonator Antenna.* RADIOENGINEERING, 2013. **22**(1).

[41] Kumar Mongia, R. and Ittipiboon, A. *Theoretical and Experimental Investigations on Rectangular Dielectric Resonator Antennas.* Antennas and Propagation, IEEE Transactions on, 1997. **45**(9): p. 1348-1356.

[42] Kishk, A. A., et al., *Numerical Analysis of Stacked Dielectric Resonator Antennas Excited by a Coaxial Probe for Wideband Applications.* Antennas and Propagation, IEEE Transactions on, 2003. **51**(8): p. 1996-2006.

[43] Rengarajan, S. R., *Reflectarrays of Rectangular Microstrip Patches for Dual-Polarization Dual-Beam Radar Interferometers.* Progress In Electromagnetics Research B, 2013. **133**(1).

[44] Mitra, D., Haque, S. K. M. and Ghosh, B. *Metal Loaded Miniaturized CPW Fed DRA*. in *Applied Electromagnetics Conference (AEMC), 2009*. 2009.

[45] Kranenburg, R.A. and Long, S.A. *Microstrip Transmission Line Excitation of Dielectric Resonator Antennas.* Electronics Letters, 1988. **24**(18): p. 1156-1157.

[46] Naragani, L. and P. H. Rao. *STUB loaded microstrip reflect array*. in *ElectroMagnetic Interference and Compatibility (INCEMIC), 2006 Proceedings of the 9th International Conference on*. 2006.

[47] Petosa, A., *Dielectric Resonator Antenna Handbook*. 2007: Artech House Publishers.

[48] Gangwar, R. K., Singh, S. P. and Kumar, D. *Comparative Studies of Rectangular Dielectric Resonator Antenna with Probe and Microstrip Line Feeds.* Archives of Applied Science Research, 2010. **2**(3): p. 1-10.

[49] Pozar, D. M., *A Reciprocity Method of Analysis for Printed Slot and Slot-Coupled Microstrip Antennas.* Antennas and Propagation, IEEE Transactions on, 1986. **34**(12): p. 1439-1446.

[50] Almpanis, G., Fumeaux, C. and Vahldieck, R. *Offset Cross-Slot-Coupled Dielectric Resonator Antenna for Circular Polarization.* Microwave and Wireless Components Letters, IEEE, 2006. **16**(8): p. 461-463.

[51] Patin, J. M. and Sharma, S. K. *Single Feed Aperture-Coupled Wideband Dielectric Resonator Antenna with Circular Polarization for Ku-Band Applications.* International Journal of Antennas and Propagation, 2012. **2012**.

[52] Jirasakulporn, P., *Multiband CPW-Fed Slot Antenna with L-slot Bowtie Tuning Stub.* International Science Index 24, 2008. **24**: p. 72-76.

[53] Keller, M. G., et al. *A Ka-Band Dielectric Resonator Antenna Reflectarray*. in *Microwave Conference, 2000. 30th European*. 2000.

[54] Jamaluddin, M. H., et al. *A dielectric resonator antenna (DRA) reflectarray*. in *Microwave Conference, 2009. EuMC 2009. European*. 2009.

[55] Jamaluddin, M. H., et al. *Dielectric Resonator Antenna Reflectarray in Ka-Band*. in *Antennas and Propagation Society International Symposium (APSURSI), 2010 IEEE*. 2010.

[56] Ujwala, D., et al., *Study of the Effect of Substrate Materials on the Performance of UWB Antenna.* International Journal of Computational Engineering Research, 2013. **3**(4): p. 252-257.

[57] Khan, A. and Nema, R. *Analysis of Five Different Dielectric Substrates on Microstrip Patch Antenna.* International Journal of Computer Applications, 2012. **5**(18): p. 6-12.

[58] Hasan, M. R. and Suman, A. A. *Substrate Height and Dielectric Constant Dependent Performance of Circular Micro Strip Patch Array Antennas for Broadband Wireless Access.* Journal of Emerging Trends in Computing and Information Sciences, 2012. **3**(10).

[59] Ismail, M. Y., Inam, M. and Zaidi, A. M. A. *Reflectivity of Reflectarrays Based on Dielectric Substrates.* American Journal of Engineering and Applied Sciences, 2010. **3**(1): p. 180-185.

[60] Yadav, A., *Microstrip Symmetrical E-shape patch Antenna for the WIreless Communication Systems.* International Journal of Emerging Technology and Advanced Engineering, 2012. **2**(12): p. 241-244.

[61] Anasri, J. A., Dubey, S. K., Singh, P., Khan, R. U.and Vishvakarma, B. R. *Analysis of U-slot loaded patch for dual band operation.* Int. J. of Microwave Opti. Technol. Lett, 2008. **3**: p. 80-84.

[62] Jedlicka, R. P., Poe, M. and Carver, K. *Measured Mutual Coupling Between Microstrip Antennas.* Antennas and Propagation, IEEE Transactions on, 1981. **29**(1): p. 147-149.

[63] Veneri, F., Angiulli, G. and Di Massa, G. *Design of Microstrip Reflectarray Using Data from Isolated Patch.* Microw. Opt. Technol, 2002. **34**(Sept 2002): p. 411-414.

[64] Pozar, D., *Microstrip Reflectarray Antennas: Myths and Realities.* International Symposium; 13th, Antennas; JINA 2004, 2004: p. 175-179.

[65] Yann, C., et al. *A Simple and Fast Technique to Analyze Accurately Reconfigurable Reflectarrays*. in *Antennas and Propagation (EUCAP), 2012 6th European Conference on*. 2012.

[66] Bakshi, K. A., Bakshi, A. V. and Bakshi, U. A. *Antennas And Wave Propagation*. 2007, Technical Publications Pune: India.

[67] Maharimi, S. F., et al., *Impact of Spacing and Number of Elements on Array Factor.* PIERS Proceedings, 2012: p. 1550-1553.