DESIGN OF A MIMO RECTANGULAR DIELECTRIC RESONATOR ANTENNA FOR LTE APPLICATION

AMIR MOAZZAMI

UNIVERSITI TEKNOLOGI MALAYSIA

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“To my beloved parents and my brother for their Guidance, support and love"

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ABSTRACT

A Broadband Multiple-Input-Multiple-Output (MIMO) Rectangular Dielectric Resonator Antenna is design and implemented. The proposed antenna consists of two ports (Aperture coupled microstrip fed using slot and Coaxial-probe) and a limited ground plane extruded on the substrate. The overall size of proposed substrate is$70 \times 60\ mm^2$ and the size of rectangular dielectric resonator antenna is$38 \times 54 \times 15\ mm^3$. The antenna is fabricated on inexpensive FR4 a dielectric constant of $\varepsilon_r = 4.3$, loss tangent tan δ=0.019 with thickness of 1.6-mm. The measured results represents that the proposed antenna obtained a reasonable bandwidth from 1.8 GHz to 2.6 GHz that could cover LTE bands application defined by 10-dB return loss. Furthermore, S-Parameters ($S_{11}, S_{12}, S_{21} and\ S_{22}$) of antenna are simulated and measured. In this project, merging the resonance frequency from the feeding mechanism and the radiating structure with assigning the air gap between DRA and substrate has been employed to broaden the bandwidth. Since both the DRA and slot radiate like a short magnetic dipole, high gain and directivity can be achieved. Simulation and measurement on the final prototype antenna were carried out and compared.

ABSTRAK

Pelbagai-Masukan-Pelbagai-Keluaran (MIMO) Resonator Dielektrik Antena (DRA) telah direkabentuk dan dilaksanakan. Antena yang dicadangkan mengandungi dua sambungan (Gandingan-pembukaan mikrostrip disambung menggunakan slot dan sambungan coaxial) dan permukaan logam yang terhad melalui substrat. Saiz keseluruhan susbtrat cadangan adalah $70 \times 60\ \mathrm{mm}^2$ dan saiz segi-empat tepat resonator dielektik antenna adalah$38 \times 54 \times 15\ \mathrm{mm}^3$. Antena ini telah difabrikasi di atas FR4 dengan tetapan dielektrik $\varepsilon_r = 4.3$, kehilangan tangen tan δ=0.019 dengan ketebalan 1.6-mm. Keputusan pengukuran menunjukkan bahawa antenna yang dicadangkan memperolehi keputusan lebar jalur yang memuaskan dari 1.8 GHz sehingga 2.6 GHz yang meliputi aplikasi LTE yang diperolehi bawah 10-dB kehilangan balikan. Sebagai tambahan, parameter-parameter S (S_{11}, S_{12}, S_{21} and S_{22}) untuk antenna telah dilakukan proses simulasi dan pengukuran. Di dalam projek ini, gabungan frekuensi resonan dari mekanisma suapan dan struktur radiasi dengan menyediakan ruang udara diantara DRA dan substrat telah dilaksanakan untuk melebarkan lebih besar lagi lebar jalur. Oleh kerana kedua-dua DRA dan slot mempunyai radiasi seperti ‘dipole’ magnetic yang pendek, gandaan dan direktiviti yang tinggi boleh dicapai. Hasil simulasi dan pengukuran untuk prototaip antenna terakhir telah dilaksanakan dan dibandingkan.

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LIST OF SYMBOLS

h	-	Dielectric substrate thickness
L	-	Length
W	-	Width
Γ	-	Reflection coefficient
Z0	-	characteristic impedance
Z_L	-	load impedance
λr	-	free-space wavelength
V_0^-	-	Reflected volta
V_0^+	-	Incident voltage
εr	-	dielectric constant of the substrate
t	-	Patch thickness
c	-	Speed of light 3x 10-8 m/s
G	-	Conductance
Л	-	*Pi*
η	-	Efficiency
G	-	Gain
D	-	Outer diameter of SMA connector
d	-	Inner diameter of SMA connector
W1	-	width of feed line

LIST OF ABBREVIATIONS

FCC	-	Federal Communication Commission
UWB	-	Ultra-wideband
PD	-	Phase Difference
CP	-	Circular polarization
AR	-	Axial Ratio
Ω	-	Ohm
dB	-	decibel
CST	-	Computer Simulation Software
FR4	-	Fire Retardant Type 4
BW	-	Bandwidth
BW%	-	Bandwidth percentage
PCB	-	Printed Circuit Boards
Hz	-	Hertz
GHz	-	Giga Hertz
mm	-	Millimeter
RF	-	Radio Frequency
IEEE	-	Institute of Electrical and Electronic Engineers
VSWR	-	Voltage Standing Wave Ratio
RL	-	Return Loss
HPBW	-	Half Power Beam Width
EM	-	Electromagnetic
UV	-	Ultraviolet

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In an age when access to information, communication and infotainment, any time, any place, anywhere has become a pre-requisite for modern life, it is not surprising that the wireless technology has been the focus of attention of technocrats and scientists.

The field of wireless communication has been undergoing a revolutionary growth for the last decade. This is attributed to the invention of portable mobile phones some fifteen years ago. The access of the second generation (2G) cellular communication services motivates the development of wideband third generation (3G) cellular phones and other wireless products and services, including wireless local area networks, home RF, Bluetooth, wireless local loops, local multipoint distributed networks etc. we can see our cities are flooded with antennas of different kinds and shapes. On the other hand for safety and portability reasons, low power, multi functional and multiband wireless devices are highly preferred. All these stringent requirements

demand the development of highly efficient, low profile and small size antennas that can be embedded into wireless products.

Over the past ten years, telecommunication industry has enjoyed tremendous growth especially mobile communications which have transformed from a luxury item to a utility as critical as electricity and water. Wireless developers around the globe are up against new challenges of accelerating growth in wireless utilization for high performing connections and reliable communication link. Revolutionary multiple antenna techniques from the base station until end-user device have been developed to improve the communications link to meet the most demanding application scenarios. In mobile communications where cost, size, weight, performance and fabrication process are constraints, low-profile antenna may be required.

In the last two decades, two classes of novel antennas have been investigated and have received considerable attention as radiating elements due their low-profile properties, simple and inexpensive for mass production and their capability to be embedded into modern wireless product. They are the Microstrip Patch Antenna (MPA) and the Dielectric Resonator Antenna (DRA). Both are highly suitable for the development of modern wireless communications. The use of dielectric resonator antenna was first proposed by Prof. S. A. Long in the early nineteen eighties. DRA has negligible metallic loss, and hence it is highly efficient than its counterpart when operated in microwave and millimeter Wave frequencies. Also low loss dielectric materials are now easily available commercially at very low cost, which attracts more system engineers to choose dielectric resonator antenna to design their wireless products. The fact that DRA can be designed for high bandwidths makes it an interesting alternative. The dielectric resonator is widely used in microwave circuits for filters and oscillators but where its resonant modes are confined and narrowband.

These two materials physical size have been investigated extensively and much effort have been put in the excitation techniques to meet required resonant frequency, polarization, pattern and impedance. In microstrip patch antenna, shape is the key parameter to increase impedance bandwidth. Various shapes of patch antenna developed to change its bandwidth as illustrated in Figure 1.1.

A rectangular shape as shown in Figure 1.1 was well-known to have wide bandwidth; Dielectric resonator antenna was found to be effective in improving antenna radiation pattern as well as bandwidth. Rectangular DR gives more flexibility to the manufacturer making it more versatile in achieving the desired bandwidth characteristics for a given resonant frequency and dielectric constant.

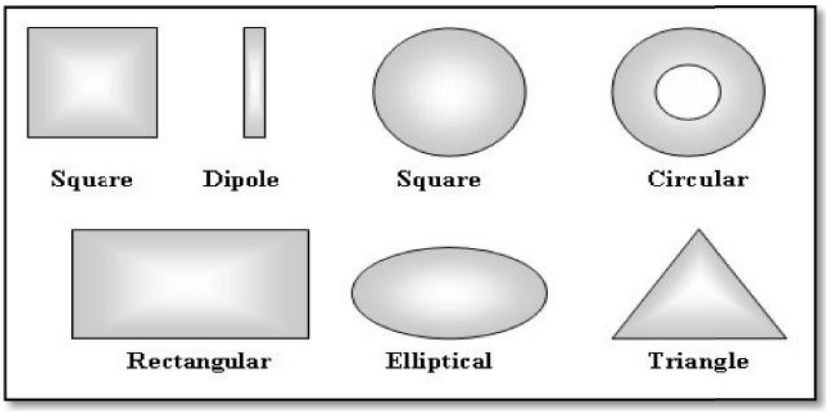


Figure 1.1: Different shape of Microstrip patch antenna

In 1993, R.D. Richmyer showed that non metalized dielectric objects can function similarly to metallic cavities which he called dielectric resonators (DRs). From the early stage of the dielectric resonator (DR) development, it has primarily been used in microwave circuits, such as oscillators and filters, where the DR is normally made of high-permittivity material, which dielectric constant ε_r>20. The unloaded Q-factor is usually between 50 and 500, making dielectric resonator (DR) widely used as an energy storage device rather than as a radiator. Significant development and efforts have been

spent and great progress has been achieved in DR filter technology since the end of 1960's. The use of high permittivity DRs to enhance the radiation resistance of electrically short probes and loops was first suggested by Sagar and Tisi in 1980. Systematic experimental investigations on dielectric resonator antennas were first carried out by Long et al (1983). Since then, theoretical and experimental investigations have been reported by many investigators on DRAs of various shapes such as spherical, cylindrical, ring, rectangular etc. Many techniques have been proposed to improve the bandwidth of DRAs, such as stacking multiple dielectric resonators, using parasitic DR elements. Recently, the multiple resonance techniques that were formerly employed in designing wideband microstrip antenna have been applied in DRA design. Along with the studies on increasing the bandwidth of the DRAs, a major area is to investigate various feed methods for DRAs. Popular coaxial feed, the direct microstrip line feed, aperture coupling using the microstrip line, perpendicular feed, and lately, the convenient conformal-strip feed have been used.

Over the last three decades, significant progress has been made in various aspects of dielectric-resonator-antenna technology, as evidenced by the more than 800 publications and over two dozen issued patents. The last few years have also seen the release of the first two books on dielectric resonator antennas. These investigations have shown the dielectric resonator antenna to be a versatile, efficient radiator, the design flexibility of which makes it an attractive alternative to traditional low-gain antennas.

Many characteristics of the DRA and microstrip antenna are common because both of them behave like resonant cavities. DRA has advantage over microstrip antenna when gain factor and antenna efficiency come into consideration. DRA offers high gain and high efficiency due to absence of conductors and surface wave losses suffered by microstrip antenna. DRAs are characterized by excellent return losses because it suffered from the dielectric loss occurring in the feed mechanism and the group plane currents.

LTE (Long Term Evolution)

Mobile broadband is becoming a reality, as the Internet generation grows accustomed to having broadband access wherever they go, and not just at home or in the office. Out of the estimated 1.8 billion people who will have broadband by 2012, some two-thirds will be mobile broadband consumers – and the majority of these will be served by HSPA (High Speed Packet Access) and LTE (Long Term Evolution) networks. People can already browse the Internet or send e-mails using HSPA-enabled notebooks, replace their fixed DSL modems with HSPA modems or USB dongles, and send and receive video or music using 3G phones. With LTE, the user experience will be even better. It will further enhance more demanding applications like interactive TV, mobile video blogging, advanced games or professional services.

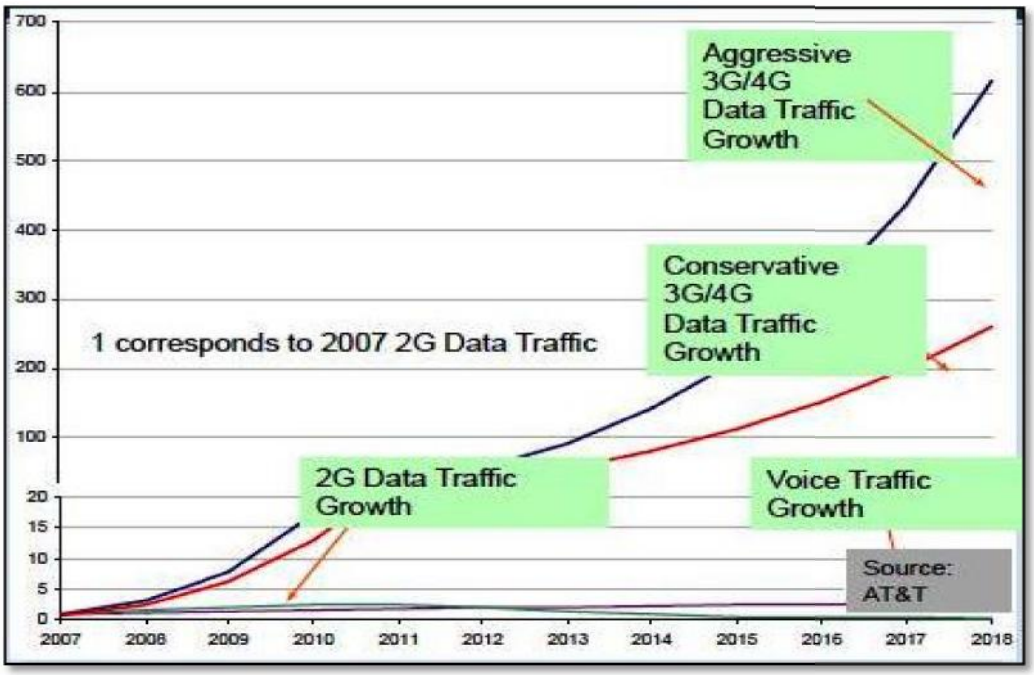


Figure 1.2: Data traffic growth forecast

LTE offers several important benefits for consumers and operators:

• **Performance and capacity** – One of the requirements on LTE is to provide downlink peak rates of at least 100Mbit/s. The technology allows for speeds over 200Mbit/s and Ericsson has already demonstrated LTE peak rates of about 150Mbit/s. Furthermore, RAN (Radio Access Network) round-trip times shall be less than 10ms. In effect, this means that LTE – more than any other technology – already meets key 4G requirements.

• **Simplicity** – First, LTE supports flexible carrier bandwidths, from below 5MHz up to 20MHz. LTE also supports both FDD (Frequency Division Duplex) and TDD (Time Division Duplex). Ten paired and four unpaired spectrum bands have so far been identified by 3GPP for LTE. And there are more bands to come. This means that an operator may introduce LTE in 'new' bands where it is easiest to deploy 10MHz or 20MHz carriers, and eventually deploy LTE in all bands. Second, LTE radio network products will have a number of features that simplify the building and management of next-generation networks. For example, features like plug-and-play, self-configuration and self-optimization will simplify and reduce the cost of network roll-out and management. Third, LTE will be deployed in parallel with simplified, IP-based core and transport networks that are easier to build, maintain and introduce services on.

• **Wide range of terminals** – in addition to mobile phones, many computer and consumer electronic devices, such as notebooks, ultra-portables, gaming devices and cameras, will incorporate LTE embedded modules. Since LTE supports hand-over and roaming to existing mobile networks, all these devices can have ubiquitous mobile broadband coverage from day one.

E-UTRA Band	Uplink (UL) BS receive UE transmit			Downlink (DL) BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1452.9 MHz	1475.9 MHz	–	1500.9 MHz	FDD
12	698 MHz	–	716 MHz	728 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
...							
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
...							
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD

Figure 1.3: LTE frequency bands

In summary, operators can introduce LTE flexibly to match their existing network, spectrum and business objectives for mobile broadband and multimedia services.

In this project, dielectric resonator antenna (DRA) is proposed to replace microstrip patch antenna since the DRA is a more effective resonator compared to microstrip patch antenna due to the absence of conductors and surface wave losses. By employing a dielectric resonator as a superstrate for the slot antenna yield a double resonant with low cross-polarization levels and identical radiation patterns. With proper design, the frequency range of LTE application can be achieved in a wide bandwidth. Rectangular DRA is proposed in this project due to its ease of analysis and simple mechanical construction.

1.2 Problem Statement

Microstrip Patch Antenna (MPA) suffer from low bandwidth, Bandwidth limitation for design is typically 2-5% this is because it radiates only through two narrow radiation slots and need a large size to make it operate. Due to this, we propose to design a new antenna based on DRA which can give high bandwidth and small size compared to basic microstrip antenna. In comparison to the microstrip antenna, the DRA has a much wider impedance bandwidth (~ 10% for dielectric constant$\varepsilon_r = 10$). This is because DRA radiates through the whole DRA surface except the grounded part. Therefore, design a new antenna based on DRA which can give high bandwidth and small size compared to basic microstrip antenna is proposed in this project. Although, that incongruity between size and impedance bandwidth still is a challenge. Furthermore, MIMO DRA explain more efficient antenna by using only one DRA and using Multiple-Input and Multiple-Output. By adjusting a proper design, it is possible for both antenna in MIMO DRA to cover the same bandwidth or different ranges.

1.3 Objective

To design, fabricate and measure a MIMO Rectangular Dielectric Resonator Antenna operating from 1.8 GHz to 2.6 GHz (for LTE application). Design specification for this project is shown in Table 1.1.

Table 1.1: Design specification

parameters	Value
Resonance Frequency	1.8 GHz – 2.6 GHz
Bandwidth Response (%)	More than 25%

1.4 Scope of Research

The scope of this project is to study proposed dielectric resonator antenna design to achieve broadband frequency response (1800MHz to 2600 MHz). The project started with the Simulation of radiation pattern and return loss and bandwidth response by using Computer Simulation Technology (CST), then by Design, fabrication and prototype measurement. Finally, parameters such as radiation pattern, return loss and bandwidth response between actual antenna and simulated design will be analyzed.

1.5 Methodology

In order to achieve target objective many approaches taken. Project workflow has been organized and simplified as shown in the flow chart in Figure 1.2. Gant charts in Table 1.2 and Table 1.3 illustrated the details of the work project in both academic semester one and two. Design methodology will be discussed in details in chapter 3.

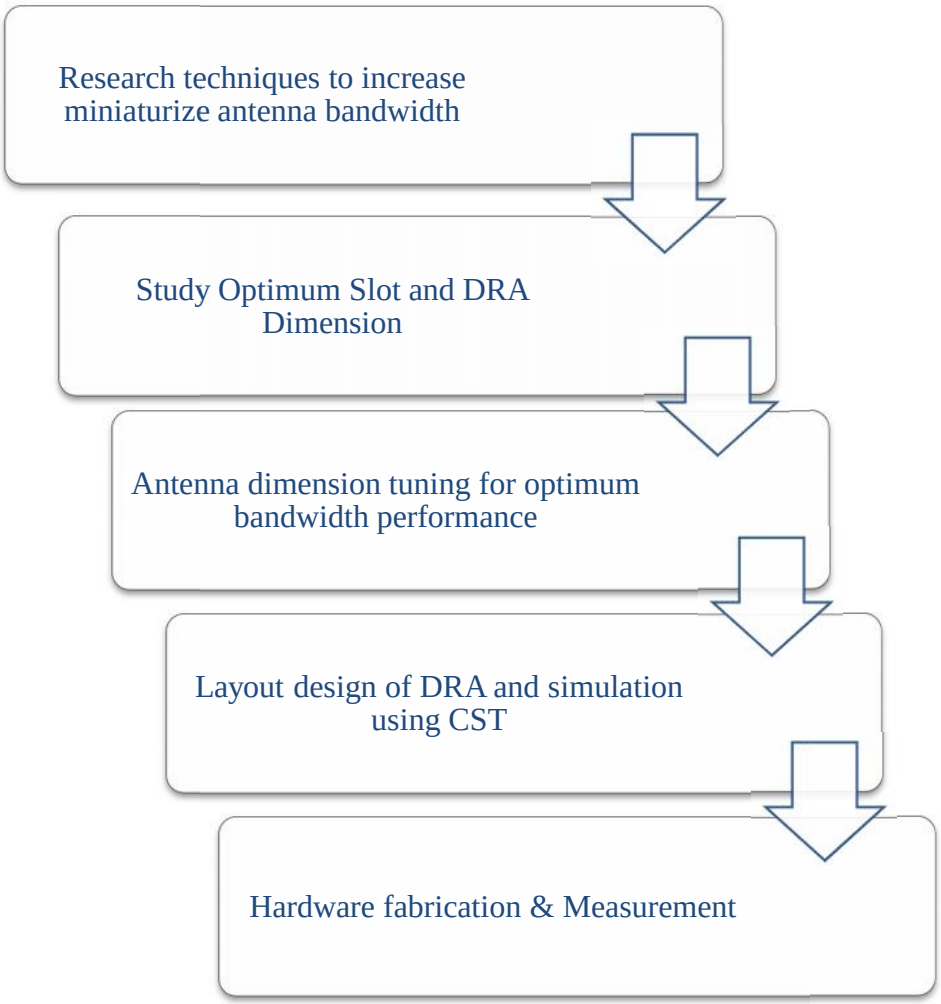


Figure 1.4: Project Overflow

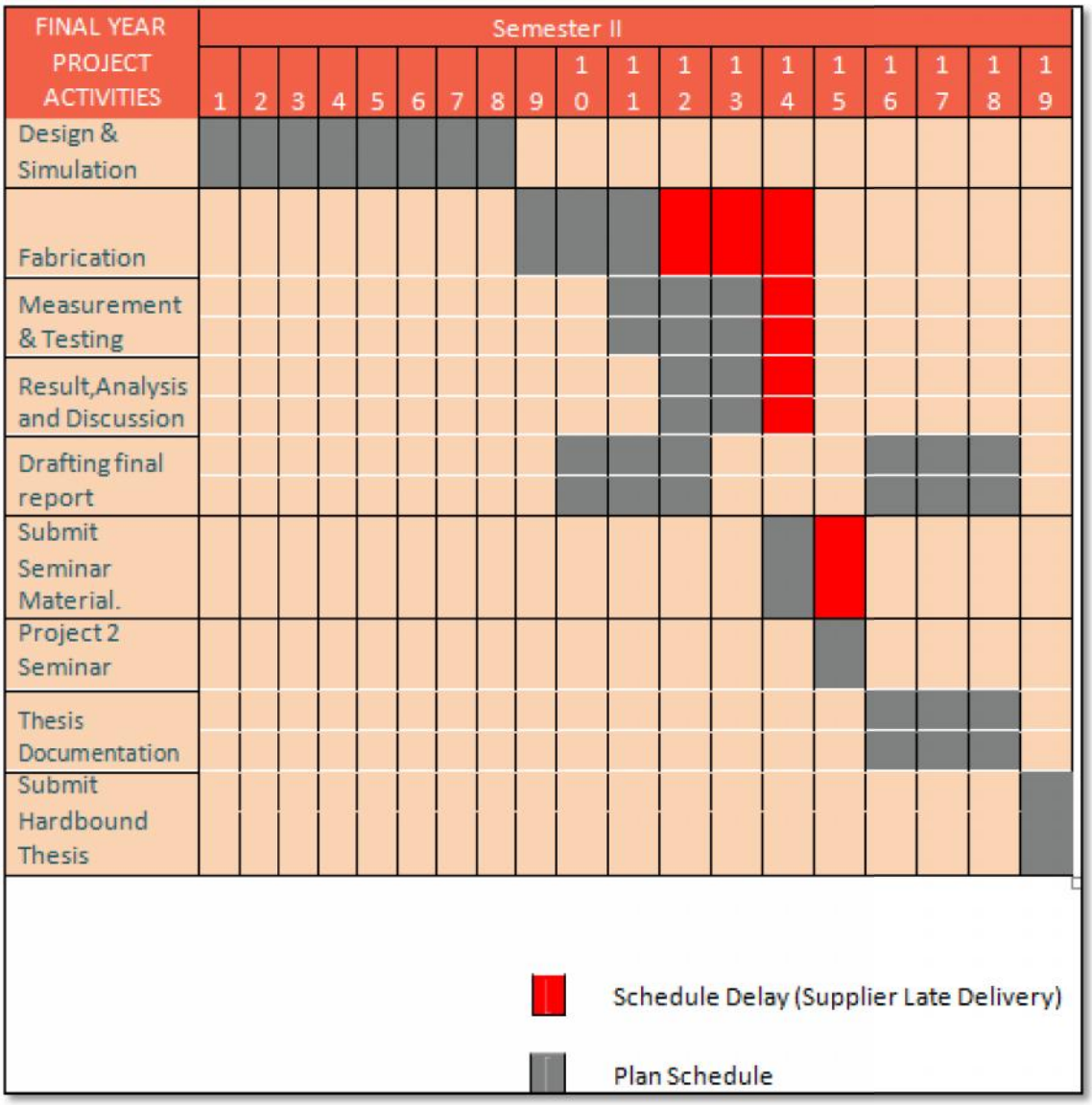
1.6 Summary

This chapter of project provides the introduction for the project and the history of antenna and microstrip antenna and brief description about DRA antenna and its advantages also describe the LTE and its advantages. It covers the objectives, scope of work and the overall flow of the project, methodology of project and finally Gant chart of the project.

Table 1.2: Gant Chart for FINAL Project Semester I

FINAL YEAR PROJECT ACTIVITIES	Semester I															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
FYP briefing session																
First meeting with supervisor																
Literature review and feasibility study of DRA fundamental																
Propose research title																
Study the simulation tools.																
Drafting literature review for report																
Parameteric Study on CST																
Project 1 Seminar																
Drafting full report																
Revise and submit FYP report for Sem I																

Table 1.3: Gant Chart for FINAL Project Semester II



REFERENCES

1. K. M. Luk and K. W. Leung, “Dielectric resonator antennas. Overview of the dielectric resonator antenna”, Research Studies Press, pp. 1-2, 2002.
2. Constantine A.Balanis, “Antenna Theory, Analysis and Design”, John Wiley & Sons Inc. Publication, 3rd ed., 2005, pg.813.
3. M. H. Jamaluddin, R. Sauleau, X. Castel, R. Benzerga and L. Le Coq, “Design, fabrication and Characterization of a DRA Reflectarray in Ka-band”, Progress In Electromagnetics Research B, vol. 25, pp. 263, 2010.
4. M.S.M.Aras,M.K.A. Rahim, A.Asrokim, M.Z.A. Abdul Aziz; “Dielectric Resonator Antenna Design for Wireless Application”; IEEE International RF and Microwave Conference ,2008.
5. Srivatsa Bhargava J; “Aperture coupled Wide-Band Micro Strip Antenna Design”; Center for Electronic Design and Technology, Indian Institute of Science, Bangalore.
6. K. M. Luk and K. W. Leung, Editors, Dielectric Resonator Antennas, Research Studies Press Ltd., Hertfordshire, England, UK, 2002
7. S. M. Shum and K.M. Luk, "Characteristics of dielectric ring resonator antenna witii air gap," Electron. Lett., vol. 30, no. 4, pp. 111-21%, Feb. 1994.
8. K. P. Esselle, "A low profile rectangular dielectric resonator antenna," IEEE Trans. Antennas Propagat., vol. 44, no.9, pp. 1296-97, Sept. 1996.
9. R. N. Simons and R. Q. Lee, "Effect of parasitic dielectric resonators on CPW/aperture-coupled dielectric resonator antennas," IEEE Proc.-H, vol. 140, pp.336-338, Oct. 1993.
10. Paper, W. (2007). Long Term Evolution (LTE): an introduction, (October).
11. K. P. Esselle, "A low profile rectangular dielectric resonator antenna," IEEE Trans. Antennas Propagat., vol. 44, no.9, pp. 1296-97, Sept. 1996.
12. Zakariyya, M. A., Sreekantan, S., Hutagalung, S. D., & Ahmad, Z. A. (2008). 3. 5 GHz Rectangular Dielectric Resonator Antenna, 189-191.
13. Ain, M. F., Hassan, S. I. S., Ismail, M. N., Othman, M. a., Jaffar, M. R., Othman, a., Sulaiman, a. a., et al. (2008). 3.5 GHz rectangular dielectric resonator antenna. 2008 IEEE International RF and Microwave Conference, 189-191. Ieee. doi:10.1109/RFM.2008.4897404

14. Denidni, T. a., & Weng, Z. (2009). Rectangular dielectric resonator antenna for ultrawideband applications. Electronics Letters, 45(24), 1210. doi:10.1049/el.2009.2210
15. Khalily, M. (2010). Wide-Band Rectangular Dielectric Resonator Antenna Design, (Apace), 2-5.
16. Ain, M. F., Hassan, S. I. S., Mandeep, J. S., Othman, M. A., Nawang, B. M., Tebal, N., & Pinang, P. (2007). 2.5 GHZ BATIO 3 DIELECTRIC RESONATOR ANTENNA M. F. Ain, S. I. S. Hassan, J. S. Mandeep, M. A. Othman and B. M. Nawang, 201-210.
17. Ishimiya, K., Langbacka, J., Ying, Z., & Takada, J.-ichi. (2008). A Compact MIMO DRA Antenna. 2008 International Workshop on Antenna Technology: Small Antennas and Novel Metamaterials, 7, 286-289. Ieee. doi:10.1109/IWAT.2008.4511338
18. Ishimiya, K., Ying, Z., & Takada, J.-ichi. (2008). A Compact MIMO DRA for 802 . 11n application, 1(1), 4-7.
19. Hong, S., Chung, K., Lee, J., Jung, S., Lee, S.-sun, & Choi, J. (2008). DESIGN OF A DIVERSITY ANTENNA Frequency [GHz], 50(5), 1352-1356. doi:10.1002/mop
20. Plicanic, V., Zhu, M., & Lau, B. K. (2010). Diversity Mechanisms and MIMO Throughput Performance of a Compact Six-Port Dielectric Resonator Antenna Array, (2007).
21. Yan, J.-B., & Bernhard, J. T. (2012). Design of a MIMO Dielectric Resonator Antenna for LTE Femtocell Base Stations. IEEE Transactions on Antennas and Propagation, 60(2), 438-444. doi:10.1109/TAP.2011.2174021
22. Progress In Electromagnetics Research C, Vol. 11, 69–79, 2009. (2009)., 11, 69-79.
23. Kishk, A. A., & Glisson, A. W. (2007). DIELECTRIC RESONATOR ANTENNA FED BY DIELECTRIC IMAGE LINE THROUGH NARROW SLOTS, 379-390.
24. [24] Note, A. (n.d.). Antenna Parameters : Antenna Gain, Directivity, and Conversion Factor, 1-4.
25. Rezaei, P., Hakkak, M., & Forooraghi, K. (2006). Design of Wide-Band Dielectric Resonator Antenna With a Two-Segment Structure. Progress In Electromagnetics Research, 66, 111-124. doi:10.2528/PIER06110701
26. So, K. K., & Leung, K. W. (2005). Bandwidth enhancement and frequency tuning of the dielectric resonator antenna using a parasitic slot in the ground plane. IEEE Transactions on Antennas and Propagation, 53(12), 4169-4172. doi:10.1109/TAP.2005.860002
27. L, P. R. (2011). A review on the design of MIMO antennas for upcoming 4G, 1(4), 85-93.
28. Rao, P. V. V. K., Vishnu, C., Reddy, V., Tejaswini, K., Babu, B. V. V. R., & Babu, K. J. (2012). A Wideband H Shape Dielectric Resonator Antenna for Wireless MIMO Systems, 1(3), 64-66.
29. Kingsley, S. P., Collins, B. S., Iellici, D., Kingsley, J. W., Keefe, S. G. O., Palmer, T. J., House, F. F., et al. (n.d.). Advancements in Antennas the development of dielectric antenna technology.

30. Rao, Q., Denidni, T. A., & Sebak, A. R. (2005). Study of Broadband Dielectric Resonator Antennas, 137-141.