DESIGN OF ARRAY DIELECTRIC RESONATOR ANTENNA FOR LONG TERM EVOLUTION APPLICATIONS

by

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SYMBOLS

dB	Decibel
dBm	Decibel with power reference of 1 mW
ε_{eff}	Effective permittivity
ε_r	Relative permittivity
λ_g	Wavelength in waveguide
Ω	Ohm
f_{res}	Resonance frequecy
c_o	Velocity of the speed of light (~ 3.0 x 10^8 m/s)

ABBREVIATIONS

3-D	Three dimensional
3G	Third generation of mobile telecommunication technology
4G	Fourth generation mobile phone mobile communication technology standards
AUT	Antenna under test
CAD	Computer aid design
CCTO	Calcium copper titanate
CST	Computer Simulation Technology
DR	Dielectric resonator
DRA	Dielectric resonator antenna
EDA	Electronic design automation
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FDD	Frequency Division Duplex
GPS	Global Positioning System
HE	Hybrid electric
HEM	Hybrid electromagnetic
HPBW	Half-power beamwidth
IMT	International Mobile Telecommunication
LTE	Long Term Evolution

MCDRA	Multilayer cylindrical DRA
MUT	Material under test
MWS	Microwave Studio
PCB	Printed circuit board
RF	Radio frequency
SRSP	Standard Radio System Plan
SWR	Standing wave ration
TDD	Time Division Duplex
TE	Transverse electric
TM	Transverse magnetic
VSWR	Voltage standing wave ratio
WLAN	Wireless local area network
WPAN	Wireless personal area network

REKABENTUK ANTENA PENYALUN DIELEKTRIK TATASUSUNAN UNTUK APLIKASI EVOLUSI JANGKA PANJANG

ABSTRAK

Disertasi ini membincangkan rekabentuk Antena Penyalun Dielektrik (APD) silinder pelbagai tatasusunan linear gandingan aperture untuk aplikasi Evolusi Jangka Panjang (EJP) 2.6 GHz. Cabaran teknikal dalam merekabentuk antena, terkandung dalam merekabentuk jalur lebar yang lebar, gandaan tinggi, antena yang padat dan prestasi cekap untuk aplikasi EJP. Kebanyakan penyelidikan rekabentuk antena komunikasi tanpa wayar menggunakan antena mikrostrip tampalan. Rekabentuk antena mikrostrip tampalan menunjukkan jalur lebar yang sempit di frekuensi operasi gelombang milimeter. Selain itu kehilangan sifat logam antena tampalan yang begitu sengit dan akan menyebabkan prestasi kecekapan antena menjadi rendah. Untuk menyelesaikan masalah ini, APD silinder pelbagai dikenal pasti sebagai calon kerana sifat kehilangan logam APD yang kurang ketara berbanding dengan antena mikrostrip tampalan dan pemalar dielektrik tinggi daripada bahan dielektrik juga menyumbang kepada pembangunan antena profil rendah pada frekuensi-frekuensi gelombang mikro. Dalam kajian ini, rekabentuk yang dicadangkan adalah APD silinder elemen tunggal suapan gandingan slot aperture, APD silinder pelbagai tatasusunan linear tiga elemen suapan gandingan slot aperture dan rekabentuk ketiga ialah APD silinder pelbagai tatasusunan linear tiga elemen tingkat bahan suapan gandingan slot aperture dengan nilai pemalar bahan dielektrik yang berbeza. Bahan-bahan dielektrik bentuk silinder itu ialah CCTO dengan nilai pemalar 55 dan Duroid 6010LM dengan nilai pemalar 10.2.

Konfigurasi APD ini dibina dengan bahan dielektrik bentuk silinder, mekanisma suapan slot aperture, satah bawah, garisan mikrostrip 50 ohm pada substrat gelombang mikro Rogers 4003 dengan nilai pemalar 3.35 dan ketinggian 0.813 mm. Kerja-kerja penyelidikan ini memberikan fokus kepada merekabentuk APD silinder pelbagai dan mencirikan prestasi APD silinder pelbagai untuk aplikasi EJP. Peralatan simulasi, perisian CST Microwave Studio (MWS) telah digunakan untuk merekabentuk, menganalisa dan menterjemahkan keluaran keputusan simulasi untuk tujuan fabrikasi perkakasan APD pelbagai. Perkakasan APD yang telah difabrikasi diukur dengan menggunakan alat penganalisa rangkaian 'network analyzer' untuk menentukan frekuensi operasi antena dan jalur lebar. Corak radiasi jarak jauh APD diukur dengan menggunakan kaedah ukuran radiasi jarak jauh antena dalaman. Frekuensi penyalun pada APD silinder pelbagai tatasusunan linear suapan slot telah diperolehi pada 2.6 GHz. Jalur lebar impedans yang diukur ialah 250 MHz dan gandaan antena simulasi dan kecekapan radiasi, e_{rad} adalah 8.29 dB dan 0.96. Keputusan simulasi dan diukur menunjukkan satu perjanjian yang baik. APD silinder pelbagai tatasusunan linear dengan pelbagai bahan dielektrik menunjukkan jalur lebar impedans diukur dengan sebanyak 232 MHz atau 8,95% dan hasil simulasi gandaan antena dan kecekapan radiasi, e_{rad} adalah 8.06 dB dan 0.95. APD silinder pelbagai yang dicadangkan telah menunjukkan prestasi yang dapat memenuhi keperluan sistem telekomunikasi mudah alih yang beroperasi dalam jalur frekuensi antara 2500 MHz hingga 2690 MHz untuk aplikasi EJP di Malaysia.

DESIGN OF ARRAY DIELECTRIC RESONATOR ANTENNA FOR LONG TERM EVOLUTION APPLICATIONS

ABSTRACT

This dissertation discusses design of aperture coupling linear array cylindrical dielectric resonator antenna (DRA) for 2.6 GHz Long Term Evolution (LTE) applications. The antenna design, technical challenge lies in designing a wide bandwidth, high gain, compact and efficient antenna performance for LTE applications. Most research on the wireless communication antenna design used microstrip patch antenna. The microstrip patch antenna design shows narrow bandwidth at millimeter wave operating frequency. Beside that the patch antenna metallic conductor loss become intense and the antenna efficiency performance may drop significantly. In order to solve this problem, the array cylindrical DRA was identified as a candidate because dielectric resonator antenna (DRA) has insignificant metallic loss compare to microstrip patch antenna and high dielectric constants of dielectric resonator also contribute to development low-profile antenna at microwave frequencies. In this research, the proposed designs were a single element slot aperture coupling cylindrical DRA, aperture coupling three elements linear array cylindrical DRA and third design was aperture coupling three elements stack materials linear array cylindrical DRA with different dielectric material constant. The cylindrical shape dielectric materials were CCTO dielectric material with dielectric constant 55 and Duroid 6010LM with dielectric constant of 10.2. The DRA configuration was used cylindrical shape dielectric resonator, slot aperture fed mechanism, ground plane, 50 ohm microstrip line on microwave substrate Rogers 4003 with dielectric constant of 3.35 and height of 0.813 mm. This research work was focused on designing aperture coupling array cylindrical DRA and characterized array cylindrical DRA performance for LTE applications. A simulation tool, CST Microwave Studio (MWS) software was used to design, analyze and translate simulated output result to array DRA hardware fabrication. The fabricated array cylindrical DRAs were measured using a network analyzer to determine antenna operating frequency and impedance bandwidth. The DRAs far-field radiation pattern was measured by indoor antenna far-field radiation pattern setup. The resonance frequency of aperture coupling linear array cylindrical DRA was obtained at 2.6 GHz. The measured impedance bandwidth was 250 MHz and simulated antenna gain and radiation efficiency, e_{rad} were 8.29 dB and 0.96. Both the simulated and measured results show a good agreement. The stack dielectric materials linear array cylindrical DRA shows measured impedance bandwidth of 232 MHz or 8.95% and simulated antenna gain and radiation efficiency, e_{rad} results were 8.06 dB and 0.95. The proposed array cylindrical DRAs were demonstrated its performance to fulfill requirements for mobile telecommunication system operating in the frequency band between 2500 MHz to 2690 MHz for LTE applications in Malaysia.

CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent fast emerged wireless communication technologies and telecommunication systems, the cutting edge antenna innovation demand for miniaturization in size, low in cost, high radiation efficiency, wide frequency bandwidth and high antenna gain design. The high speed data centric and performance wireless communication systems are crucial with required an efficient antenna structure. For instance, 3rd generation (3G) network system, handheld mobile smart phone, portable personal computer and table computer download from wireless internet access, email and multimedia information exchange over Bluetooth or WI-Fi IEEE 802.11x (Conti, 2007). Thus antennas become an important component in the next generation of high performance communication systems.

Moreover, moving beyond 3G networks, next generation wireless mobile systems Long Term Evolution (LTE) and LTE-Advanced 4G were sure features with a significant level of improvement in performance and capabilities respect to current deployed 3rd generation system. For future generation or systems 4G, it is anticipated that these potential new wireless communication interfaces will support up to approximately 100Mbps for high mobility and up to approximately 1Gbps for low mobility such as nomadic/ local wireless access (Hara and Prasad, 2003).

In conjunction with the future development of wireless systems, there will be an increasing interaction between radio communication networks, such as wireless personal area networks (WPANs), wireless local area networks (WLANs), digital broadcast, and fixed wireless access (Hara and Prasad, 2003). An advance antenna system is nonetheless critical element for establishing and achieves a reliable performance of wireless radio communications. For this reason, developing a robust, low profile, high efficiency antenna is very crucial for many more future wireless product applications are possible.

The early research on practical application of dielectric resonators (DRs), to microwave circuit filters began in the late 1960s (Harrison, 1968). After that investigation on dielectric resonator antenna (DRA), has been first introduced by Long (1983). Since after that a comprehensive research had been carried out in application of DRA for wireless applications. The DRA is a non-metallic structure that constructed from a high permittivity dielectric material. Due to there are no conductor or surface-wave losses on DRA, therefore it has a very high radiation efficiency (> 95%). The high degree of flexibility parameters from DRA, such as various shapes, size and dielectric material constant can be used to design an efficient performance wireless application (Petosa, 2007). This research would highlight on the study of array aperture couple cylindrical dielectric resonator antenna (DRA) for wireless application.

1.2 Problem Statement

Dielectric resonator antennas (DRA) are widely studied for various wireless communication applications (Cormos, 2003). Beside DRA, microstrip patch antenna also used for development of wireless communication. A design of dual-band microstrip patch array antenna design for LTE and WLAN application was shown narrow bandwidth of 75 MHz at 3 GHz (Lakshmipriya, 2012). At a millimeter wave high frequency, the patch antenna metallic conductor loss become intense and the antenna efficiency performance may drop significantly. In order to overcome this problem, dielectric resonator antenna is identified as candidate for wireless communication system design. The DRA has insignificant metallic loss compare to microstrip patch antenna so it is favorably efficient at operated millimeter wave frequencies. High dielectric constants of dielectric resonator also contribute on produce low-profile antenna relative to the large size of microstrip patch antenna at microwave frequencies (Luk and Leung, 2003). In this research, the discussed problem of narrow bandwidth would be targeted and solving by realizing wideband and high antenna gain performance DRA for LTE application operated at 2.6 GHz. In this research, study on 2.6 GHz slot aperture coupling microstrip line feed linear array cylindrical DRA design would be investigated. The investigation would focus on small, compact DRA with reduced unwanted coupling from excitation network and optimize input impedance matching configuration to higher bandwidth and antenna gain performance.

1.3 Thesis Aim and Objectives

The objectives of this research are listed as below:

1. To design slot aperture coupling cylindrical dielectric resonator antenna (DRA) for 2.6 GHz LTE applications. Further investigate characteristics of slot aperture coupling cylindrical DRA.
2. To design and simulate slot aperture coupling linear array cylindrical DRA with 3 elements dielectric resonator for 2.6 GHz LTE applications. Further characterize array DRA performance by CST Microwave Studio simulation tool.
3. To design a novel wideband slot aperture coupling 3 elements stack materials linear array cylindrical DRA consist of two different material dielectric constants for 2.6 GHz LTE applications. Further characterize wideband array cylindrical DRA and verify its simulated and measured hardware results.

1.4 Thesis Outline

In this thesis, two concept design of 3 elements planar linear array aperture coupling cylindrical DRAs with half- lambda spacing are proposed. The 2.6 GHz linear array aperture coupling cylindrical DRAs can be categorized into two major parts. The first part is software which involves Computer Simulation Technology (CST) Microwave Studio. The CST software is used to investigate, design and simulate the aperture coupled cylindrical DRA according to the design specification and research objective requirements.

The design work packages consist of calculation and simulation 50 ohm input impedance microstrip waveguide feed mechanism, rectangular slot aperture dimension design, dielectric resonator dimension design to resonate at 2.6 GHz and CCTO dielectric material characterization for its dielectric constant (ε_r = 55) and lost tangent. The results of the simulation will be verified in terms of its influence on return loss for antenna operating bandwidth, far-field radiation pattern including antenna gain.

Second part is on hardware fabrication and validation work packages. The best given results from simulation for each step will be fabricated into the microstrip PCB board together with cylindrical dielectric resonator antennas. Comparison between both CST MWS simulation result and the hardware validation result will give a concrete conclusion of this investigation on the performance of linear array aperture coupled DRAs with high antenna gain performance. Furthermore a novel wideband linear array aperture coupled DRA also be presented using two different dielectric constants material stacking methods as dielectric resonator elements to achieve its enhancement of wide bandwidth performance.

1.5 Limitation of Research

In this research work, design of compact and low-profile DRAs are always in consideration of its application effectiveness to wireless communication operation peripherals or equipments which required an outlook with compactness and slickly design in general. Theory of electrical small antenna is used to establish the fundamental limitation of antenna gain and bandwidth of this research. The theory is applied to predict theoretical performance of gain and bandwidth based on the maximum size of dielectric resonator (Petosa, 2007).

A design of physical large infinite ground plane is not possible to accommodate in these DRAs designs and application. A small ground plane may produce large ground current incident on its edges, thus resulted ripples in DRA radiation patterns and suffered to the significant amount of scattering that may cause antenna gain degradation and decreased in bandwidth (Petosa, 2007). In this research, the design of the DRAs ground plane has assumed that it was infinite in the analysis.

As a full anechoic chamber with measurement equipments are required to measure DRA hardware absolute gain parameter in this research work and it was not yet a facility on university premises. Thus the antenna gain parameter characterization can be done with CST MWS simulation. Beside that far-field radiation pattern of DRA can be measured by using indoor laboratory radiation pattern measurement equipment setup to perform the test.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of DRA

In this chapter, it organizes with an introduction of basic shapes dielectric resonator antenna (DRA), feeding techniques to excite a DRA, dielectric resonator resonance modes and electric and magnetic field distribution. The DRA has low-loss characteristic at millimeter wave operating frequency, the characteristic is highly advantageous for high-gain and wideband applications. There are many recent investigations and development in this emerging antenna technology for mobile communication system, especially the latest LTE mobile technology applications.

2.1.1 Basic Shapes of DRA

Simple shapes of DRA that most commonly used are cylindrical, hemispherical and rectangular. If a dielectric resonator unshielded by metal cavity and with proper excitation to launch appropriate radiation mode, these same dielectric resonators can become an efficient radiator. Furthermore, by lowering dielectric constant ε_r of the DRA, the radiation can be kept over a broad band of frequencies (Petosa, 2007). It was found that DRA operating at fundamental modes radiate like a magnetic dipole, independent of their shapes (Luk and Leung, 2003). Figure 2-1 shows picture of basic shape DRA.

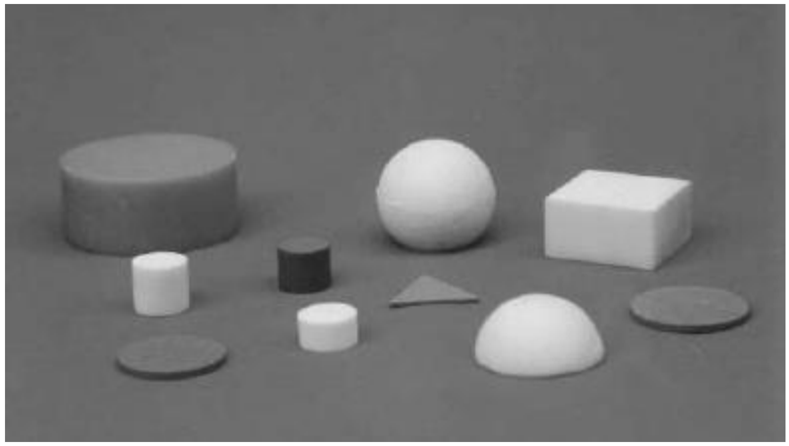

Figure 2-1 Picture of basic DRA shapes (Luk and Leung, 2003)

2.1.2 Hemispherical DRA

Hemispherical DRA is the shape consists of limited practical value due to the difficulty involved in material fabrication and lack of any degree of freedom in choosing design parameters. For a material with given dielectric constant, the radius of the sphere will determine both the resonance frequency and radiation Q-factor. This designer has no control over size and bandwidth of the antenna. The electromagnetic resonant modes exist in a dielectric sphere is transverse electric (TE) and transverse magnetic (TM). When a radial *r* component of electrical field is zero value, it characterized as the TE mode and TM mode have a zero radial *r* component of magnetic field (Petosa, 2007). Figure 2-2 shows a picture of the hemispherical shape DRA.

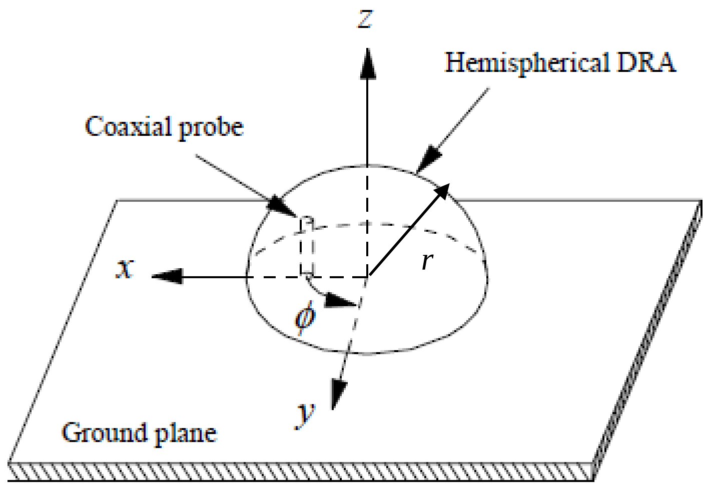

Figure 2-2 Hemispherical shape DRA (Luk and Leung, 2003)

2.1.3 Cylindrical DRA

The cylindrical shape of DRA offers greater design flexibility with its ratio of radius/height controls the resonance frequency and Q-factor. For a given material dielectric constant and resonance frequency, different Q-factors can be obtained by varying the aspect ration of DRA's dimensions. For the cylindrical shape DRA, material fabrication is also simpler compared to hemispherical DRA. The resonant modes TE, TM and hybrid electric (HE) modes can be excited within the cylindrical DRA for results in either broadside or omnidirectional radiation patterns (Petosa, 2007). To excite HEM_{11} mode, a slot excitation is centered with the DRA axis and the microstrip transmission line also centered to the slot (Luk and Leung, 2003). Figure 2-3 shows a picture of the cylindrical shape DRA.

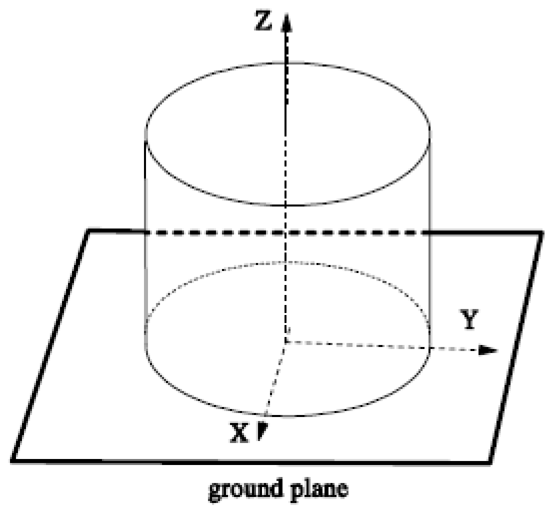

Figure 2-3 Cylindrical shape DRA (Luk and Leung, 2003)

2.1.4 Rectangular DRA

The rectangular shape DRA offers the greatest design flexibility of the three basic shapes, by having two degrees of freedom length/width and depth/width. For a material with fixed dielectric constant, a few dimensions aspect ratios can be chosen to all resonate at a given frequency, while offering different radiation Q-factors. The resonant modes in an isolated rectangular dielectric resonator can be divided to TE and TM. Figure 2-4 shows a picture of the rectangular shape DRA (Petosa, 2007).

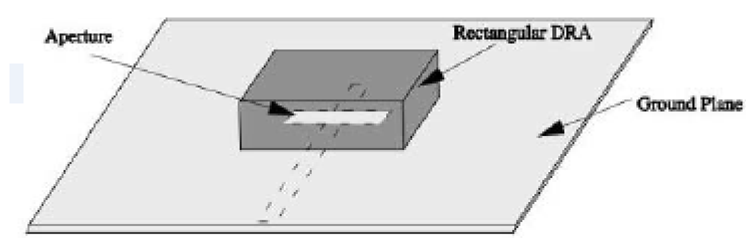

Figure 2-4 Rectangular shape DRA (Luk and Leung, 2003)

2.2 Antenna Feeding Mechanisms to Dielectric Resonator

There were number of feeding mechanisms used to excite the DRAs have been developed and widely studied. The methods used for DRAs excitation such as aperture-coupling, coaxial probe, microstrip feedline, co-planar feed and dielectric image guide (Luk and Leung, 2003). The type of feeding mechanism used and its location with respect to the DRA were playing an important factor in determining which excited modes and later it will determine the input impedance and radiation characteristics of DRAs (Petosa, 2007).

2.2.1 Aperture Coupling

Typically feeding method for DRAs is excitation through an aperture in the ground place where located between microstrip or coaxial feed-line and dielectric resonator. The aperture coupling method is applicable to DRAs of any shape. The aperture behaves like a magnetic current running parallel to the length of the slot, which excites magnetic fields in the DRA. This coupling method has the advantage of having electrically small slot dimensions that can minimize the amount of radiation spilling beneath the ground plane. The microstrip or coaxial feed network located below the ground plane has advantage to avoid spurious radiation from the feed. It can be easily achieved a strong coupling level by moving the DRA with respect to the slot (Petosa, 2007).

An input impedance of cylindrical DRA excited by an aperture slot was studied and obtained from the equivalent magnetic current on the slot. The slot aperture was properly adjusted to couple strongly to the desired resonance mode and to achieve proper matching with excitation source. Aperture coupled DR antennas have advantages over coaxial probe fed DR antennas in terms of bandwidth and in reduction of ohmic losses (Gregory, 1994). Figure 2-5 shows the DRA located on an infinite ground plane over an aperture slot by Gregory.

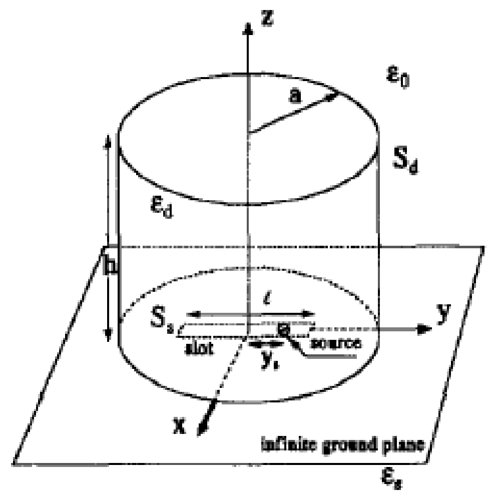

Figure 2-5 Aperture slot coupling fed to cylindrical DRA (Gregory, 1994)

2.2.2 Coaxial Probe

Besides aperture coupling, another common method use for coupling to DRAs is with a probe consists of center pin of a coaxial transmission line that extends through a ground plane. The probe was considered as a vertical electrical current, for coupling purposes, it should be located in a region where DRA having high electrical fields to achieve strong coupling between fed network to the DRA. The coupling magnitude between probe source and electrical field within DRA can be determined by reciprocity theorem with proper boundary condition (Petosa, 2007). To improve impedance matching and coupling level can be optimized by adjusting the probe height and the DRA location. Normally the probe can either be located adjacent to the DRA or can be embedded within it. Also, depending on the location of the probe, various modes can be excited (Petosa, 2007). Figure 2-6 shows the configuration of adjacent probe coupling to cylindrical DRA.

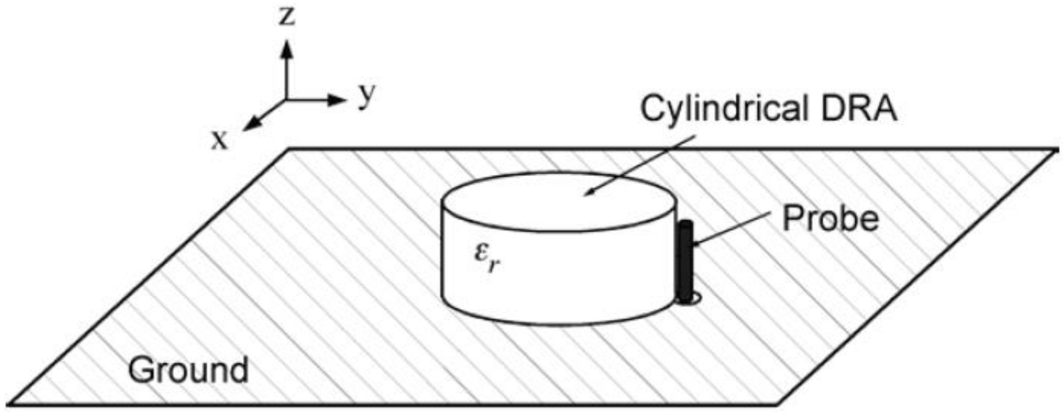

Figure 2-6 Configuration of probe coupling to cylindrical DRA (Petosa, 2007)

2.2.3 Microstrip Feed-line

The microstrip feed-line is also a common method used for coupling to a dielectric resonator antenna. DRA locate by proximity coupling to microstrip feed-line in microwave circuit design. The amount of coupling from the microstrip line to DRA can be controlled by adjusting the relative spacing between the DRA and the line for side-coupled configuration or length of the line underneath the DRA for direct-coupled configuration. A more dominant parameter affecting the degree of coupling is the dielectric constant of the DRA. In order to achieve a strong coupling level, dielectric constant ε_r of DRA should use higher value than 20 (Petosa, 2007). Figure 2-7 shows the microstrip line feeding technique applied to DRAs.

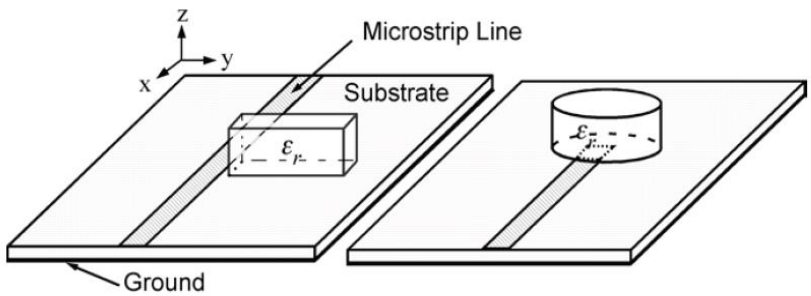

Figure 2-7 Microstrip line coupling to DRAs (Petosa, 2007)

2.3 Field Distributions and Resonance Modes

In DRA, it can be exciting for the different modes to produce different radiation characteristics like radiation patterns. It is important to comprehend near field distribution of DR which could help to determine the proper method to couple to a particular resonance mode. Once the resonant frequency is determined for a particular azimuthal mode of a source-free system, the equivalent surface currents can be computed in the complex frequency plane and consequently both the near field and far field can be computed for this particular mode. Thus near field distribution of DR would determine a particular mode could be excited by proper excitation method (Luk and Leung, 2003).

In the previous section of the antenna feeding mechanism discussed about various feeding mechanisms can be used for excitation to couple energy to DRAs. For example, probe fed can be used to couple to the electric field lines when it is oriented along electric field line and an aperture can couple along magnetic field lines inside DR. The near field distributions of four modes are TM_{01}, HEM_{11}, TE_{01} and HEM_{12}. The electric and magnetic field line in perpendicular planes respectively, for the four modes are shown in Figure 2-8 and assumed that there is no ground plane (Luk and Leung, 2003).

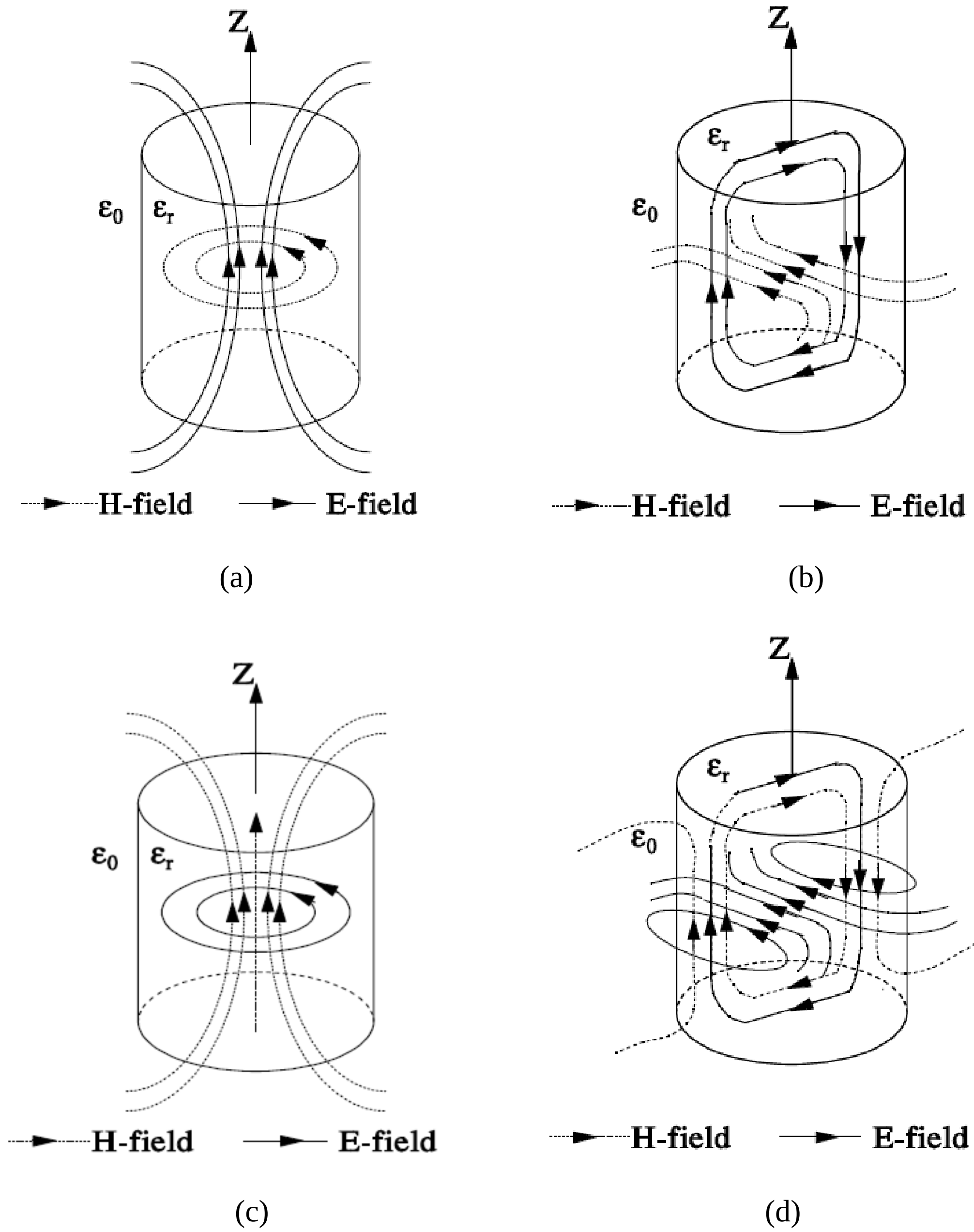

Figure 2-8 Field distribution of (a) TM_{01}, (b) HEM_{11}, (c) TE_{01} and (d) HEM_{12} modes (Luk and Leung, 2003)

A rectangular slot aperture coupling method can be used to excite the $HEM_{11\delta}$ mode of a cylindrical DRA, as shown in Figure 2-9 (Petosa, 2007). The slot aperture must be properly adjusted to couple strongly with desired mode and to achieve proper matching with excitation source.

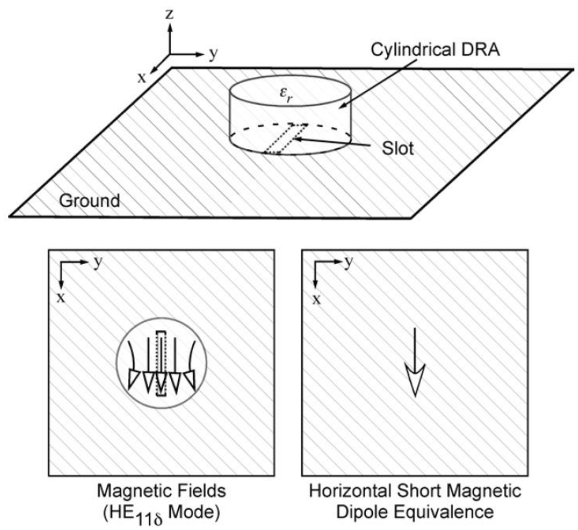

Figure 2-9 Aperture coupling cylinder DRA of $HEM_{11\delta}$ mode (Petosa, 2007)

2.3.1 Theory and Analysis of DRA

Different resonant modes can be excited in DRA to get different antenna radiation patterns. There are three different resonant modes can be excited in dielectric resonator are transverse electric (TE), transverse magnetic (TM) and hybrid electromagnetic (HEM) modes. In theories, the three types of excitation modes have an infinite number of resonant modes in each group and desired mode is usually chosen based on the application requirements.

2.3.2 Resonance Frequency

An analysis for cylindrical DRA had been performed using the magnetic wall boundary model to analyze DRA internal and external field mechanisms and predict the resonance frequency (Long, 1983). The cylindrical DRA configuration and standard coordinates as shown in Figure 2-10.

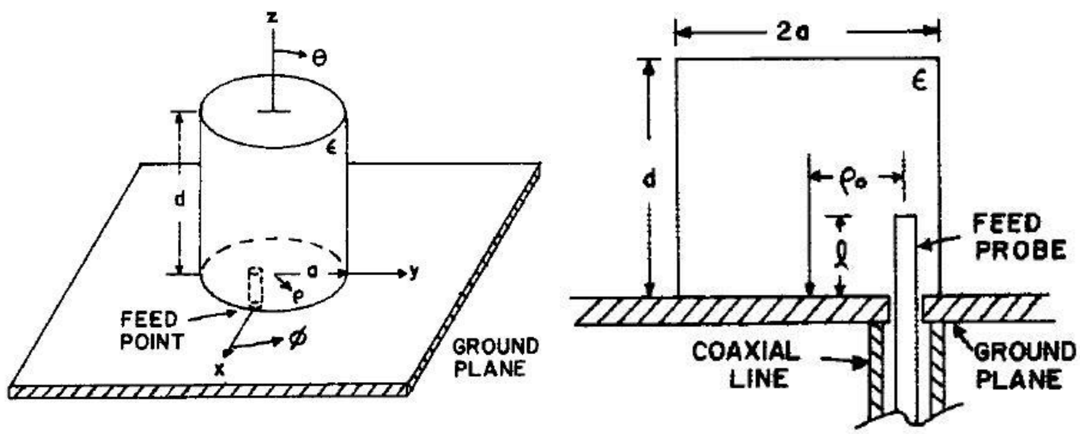

Figure 2-10 Configuration of cylindrical DRA structure (Long, 1983)

In the analysis, assuming that the DRA surfaces are perfect magnetic conductor with a feed probe is temporarily ignored and the cylindrical cavity is considered uniform. For such a cavity, the resonance frequency of npm mode is given in Equation 2.1 (Long, 1983).

$$f_{npm} = \frac{1}{2\pi a\sqrt{\mu\varepsilon}}\sqrt{\begin{Bmatrix} X_{np}^{2} \\ X_{np}^{'2} \end{Bmatrix} + \left[\frac{\pi a}{2d}(2m+1)\right]^{2}} \qquad (2.1)$$

where *a* is radius of the cylindrical DRA, *d* is height and X_{np} is the Bessels's function.

The resonance frequency found can be on any type of modes. In practical applications, the dominant mode use is the fundamental resonant mode because it has the lowest resonant frequency. The dominant mode found is the TM_{110} mode and the resonance frequency is given in Equation 2.2 (Long, 1983).

$$f_{TM_{110}} = \frac{1}{2\pi a\sqrt{\mu\varepsilon}}\sqrt{X'^{2}_{11} + \left(\frac{\pi a}{2d}\right)^2} \tag{2.2}$$

where $X'_{11} = 1.841$

A cylindrical DR antenna fed by aperture-coupling method with hybrid electromagnetic mode (HEM) is analyzed by Martin (1990). Figure 2.11 shows the aperture-coupling DRA structure configuration.

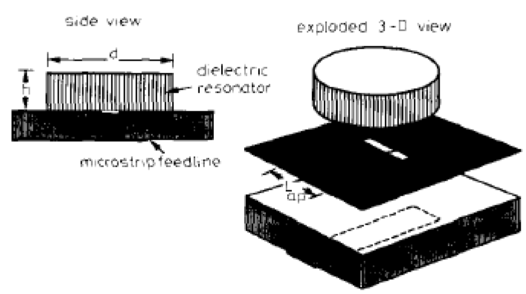

Figure 2-11 Configuration of aperture coupling fed method DRA (Martin, 1990)

The main mode excited for the cylindrical DRA is $HEM_{11\delta}$ and the resonance frequency is given in Equation 2.3 (Martin, 1990).

$$f_{res} = \frac{c_o}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left[\left(\frac{3.682}{d}\right)^2 + \left(\frac{\pi}{2h}\right)^2\right]} \quad (2.3)$$

where

f_{res} is the resonance frequency

C_o is velocity of the speed of light (~ 3.0×10^8 m/s)

ε_r is permittivity of the dielectric resonator

d is diameter of the dielectric resonator

h is height of the dielectric resonator

2.4 Overview of DRAs

The term “dielectric resonator” (DR) has been found via a un-metallize dielectric object can function as microwave resonators much like a metallic cavity in 1930s (Richtmyer, 1939). In the late 1960s, dielectric resonator is widely used in microwave circuitry applications such as DR filters (Cohn, 1968) and oscillators (Petosa, 2007). The DR microwave elements were normally made of high dielectric constant material with high quality factor and low temperature coefficient. The relative dielectric constant (ε_r) for DR normally is more than 20 and Q-factor can range from 50 to 10000 (Leung, 2003). The interest in the DR for microwave circuit on stabilization always presents as an energy storage dielectric device rather than as a resonance radiator.

However, it was well known that an open DRs at free-space boundaries were found to resonate in various modes (Fiedziuszko, 1982). But it was no idea taken on to apply DRs as resonator antenna until the first cylindrical dielectric resonator antenna (DRA) was published by Long, in 1983. At the time after, DRA became a popular research topic for antenna designers because of its no inherent conductor loss and compact size advantages over microstrip patch antennas. In the early 1980s, studies of dielectric resonator as antenna elements were conducted to examine characteristics of different type of DRAs. The characteristic of a cylindrical DRA investigate by Long (1983), characteristic of a rectangular type DRA investigate by McAllister (1983) and characteristic of a hemispherical DRA investigate by McAllister (1984). A study also reported in early 1990s, DR placed in an open environment can exhibit low values of radiation Q-factor and thus it is useful as a resonator antenna (Mongia, 1993). The first cylindrical DRA designed by Long is shown in Figure 2-12.

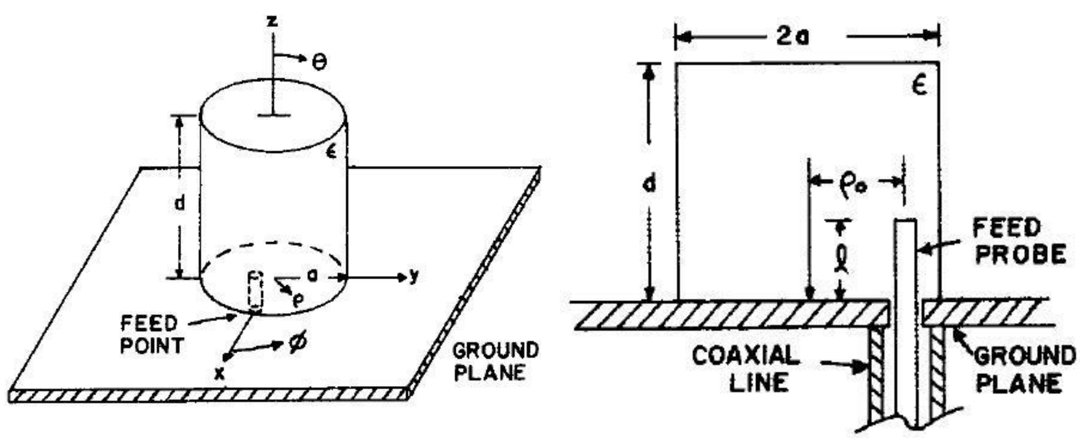

Figure 2-12 Probe fed cylindrical DRA structure (Long, 1983)

Later a dielectric resonator antenna used aperture coupling excitation configuration was investigated and confirmed its effectiveness and practical performance. It consists of a circular cylindrical DRA fed by a microstrip feedline through a coupling aperture in the ground plane as shown in Figure 2-13.

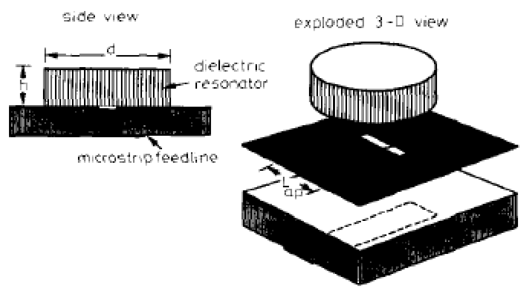

Figure 2-13 Aperture coupling circular cylindrical DRA structure (Martin, 1990)

The cylindrical DRA operate at millimeter wave frequencies between 14 and 16 GHz (Martin, 1990). A cylindrical DRA based on $CaCu_3Ti_4O_{12}$ (CCTO) dielectric material with a dielectric constant of 62 and frequency operation around 4.6 GHz was presented. The performance of the CCTO cylindrical DRA was examined and its measurements confirm the potential use of the dielectric material for DRAs (Almeida, 2007). Figure 2-14 illustrate the CCTO cylindrical DRA configuration with coaxial probe feed.

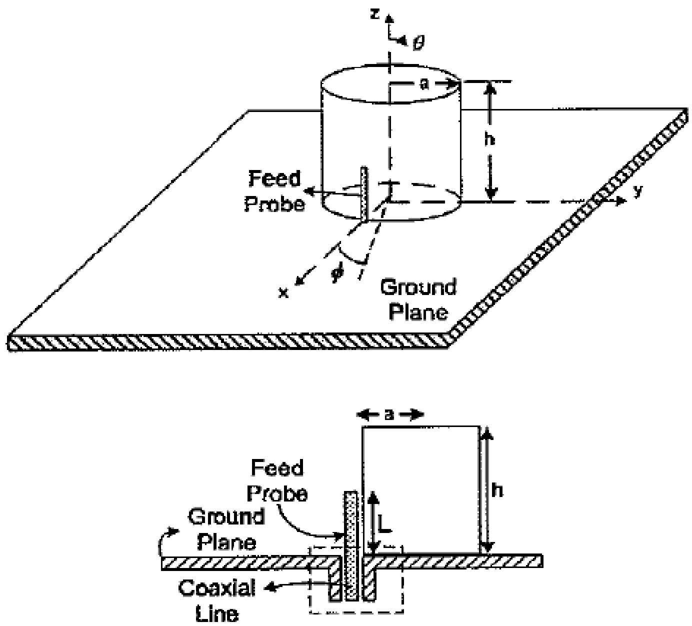

Figure 2-14 Configuration of CCTO cylindrical DRA (Almeida, 2007)

2.5 Wideband DRA

For wireless application technologies, there are like mobile cellular, Wi-Fi, Bluetooth, WiMAX, GPS etc. use a wide spectrum frequency band in today's communication systems. A lot of research has been carried out on bandwidth enhancement in DRAs. The bandwidth enhancement of DRA depends on design parameters such as excitation method, DR shape and dimensional parameter and relative dielectric constant of DRA material use. Different methods have been discussed for bandwidth enhancement; it reveals that low dielectric constant DRA with slot coupling gives more compact design with increased bandwidth due to dual resonance characteristics. DRA array also another technique to enhance bandwidth with multiple resonances which is useful for broadband applications (Sharma, 2011).

An idea has been investigated for increasing bandwidth by stacking two elements cylindrical DRA of different dielectric constant compare to a single cylindrical DRA. The result shows that for stack two elements DRA configuration has achieved more than 25% bandwidth for SWR < 2 and single cylindrical element DRA estimate only 10% bandwidth corresponding to SWR < 2 (Kishk, 1989). The cylindrical DRA configuration of stacking two elements cylindrical DR is shown in Figure 2-15.

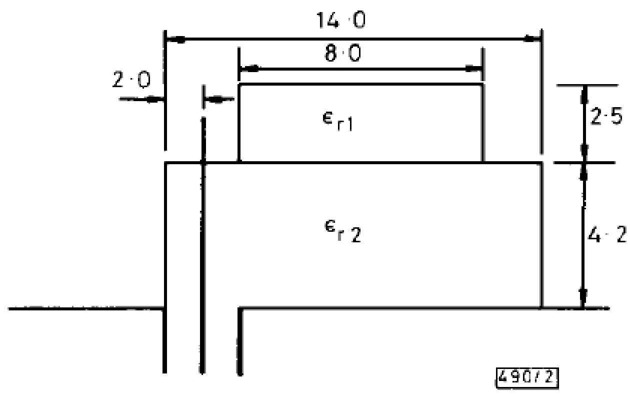

Figure 2-15 Stack materials cylindrical DRA excited by coaxial probe (Kishk, 1989)

A simple cylindrical DRA of wideband design using aperture coupling and probe feeding method were investigated. Result from a conclusion, matching bandwidth of the DRAs were enhance by probe fed method give 26.8% and aperture coupled method achieved 23.7%. It was done with chosen the radius to height ratio (*r/h*) at 0.329 of the cylindrical DRA. The excited two fundamental modes were given similar radiation characteristics at close resonance frequencies, resulting in wideband behavior (Chair, 2005). Figure 2-16 shows the cylindrical DRAs configuration for coaxial fed and aperture fed.

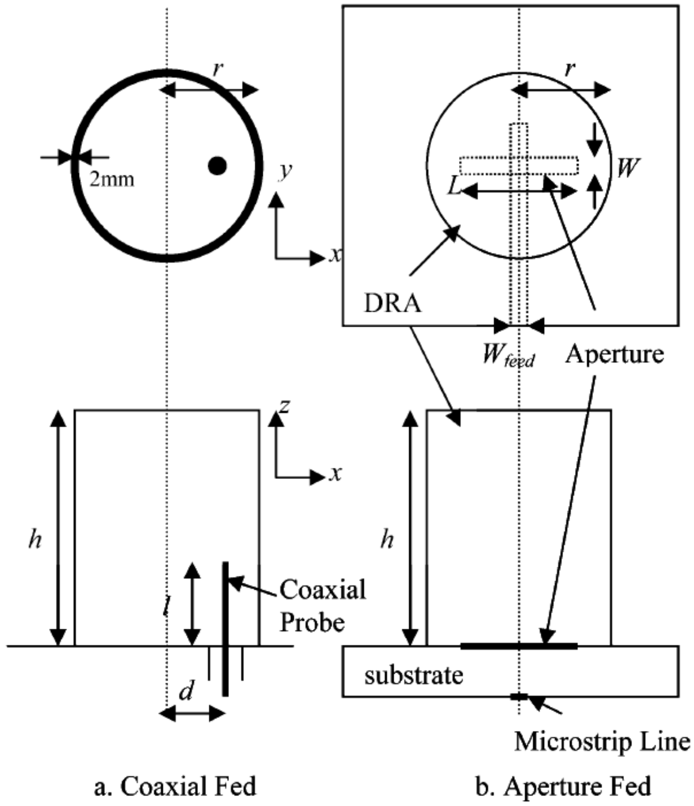

Figure 2-16 Configurations of the cylindrical DRAs for coaxial fed and aperture fed (Chair, 2005)

A new non-homogenous DRA, multilayer cylindrical DRA (MCDRA) to achieve wide bandwidth has been designing and investigated by Huang and Kishk, 2007. The design used three different cylindrical dielectric resonator stacked on top of each other. For coaxial probe fed method, matching bandwidth achieved around 66%. Higher than 32% of matching bandwidth achieved with aperture coupled microstrip fed mechanism. Both excited methods presented with a broadside radiation pattern. Design by using a probe fed mechanism DRA, one can get wide bandwidth, but it is a complex design and fabricated structure. Figure 2-17 shows the configuration of MCDRA with the finite ground plane.