Dielectric Resonator Antenna (DRA) for Wireless Application

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Abstract — This paper describes a simple design on dielectric resonator antenna using disk shape. The dielectric resonator antenna (DRA) consists of high dielectric constant materials, high quality factors and mounted on a grounded dielectric substrate of lower permittivity. The selected dielectric disk is operating at frequency of 2.4 GHz with dielectric constant of 34.73. The miscrostrip transmission line has been used as a feeding line for the resonator. The simulation process was done using Computer Simulation Technology (CST) Microwave Studio and Microwave office. The antenna has been fabricated on the FR-4 microstrip board using the wet etching technique. The DRA is operating at the frequency bands used for IEEE 802.11b/g Wireless LANs. The performance between simulation and measurement give a very good approximation result.

Keywords— Dielectric Resonator Antenna, Dielectric Resonator, Transmission line feed, Microstrip line.

1. INTRODUCTION

Dielectric Resonator Antenna (DRA) is fabricated from low-loss and high relative dielectric constant material of various shapes whose resonant frequencies are functions of the size, shape and permittivity of the material. DRA can be in a few geometries including cylindrical, rectangular, spherical, half-split cylindrical, disk, and hemispherical shaped. Richmyer proved the fact that dielectric resonators radiate energy in 1939 however practical application did not take place until the 1960's when suitable dielectric compounds became available [1]. Dielectric resonators were first popular as filter elements devices in microwave circuits with the first reported use as a radiating element not until the early 1980's when the smaller size potential and higher frequency applications boosted the research into the dielectric resonator antenna. The DRA has some interesting characteristics, like the small size, ease of fabrication; high radiation efficiency, increased bandwidth and low production cost, and DRA are very promising for application in wireless communications.

The advantages of the DRA are stated briefly as:

- Smaller circuit sizes and reduction of overall circuit costs with comparable performances.
- DRA can be designed in any 3D shape as shown in Figure 1. Having more geometric parameters add more degrees of freedom to the design.

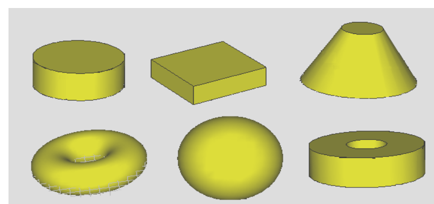

Figure 1: Basic geometrical shapes of dielectric resonators.

- The DRA is made up of high dielectric constant with no conducting parts and has very small dissipation loss. Therefore, it can handle high power. The limitation might be caused by the excitation mechanisms.

- Its physical size is small since DRA is made of high dielectric constant. Therefore, the DRA size decreases as the dielectric constant increases.

- DRA is not limited to linear polarization. The DRA can be designed for single, dual, or circular polarization.

DRAs offer several attractive features including:

- High dielectric constant $\varepsilon_r = 20 – 100$
- High radiation efficiency (≈ 95%) due to the absence of conductor or surface wave losses
- Wide control over size and bandwidth
- Tight ε_r tolerance: ± 1- 5%,
- High quality factor Q: up to 10000 (f = 10GHz)

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- Wide frequency range: f = 0.7 - 35GHz
- Wide range of temperature coefficient of resonance frequency: τ_f = (-12…+30) ppm/ ^{o}C
- Tolerance τ_f = ± 0.5; ±1.0; ±2.0 ppm/ ^{o}C

2. DIELECTRIC RESONATOR ANTENNA DESIGN

The summary of the design for DRA is shown in Figure 2. In simulation, two methods has been introduced such as layout design which is called Method of Moments (MoM) and circuit design using circuit simulator or Transmission Line Model (TLM).

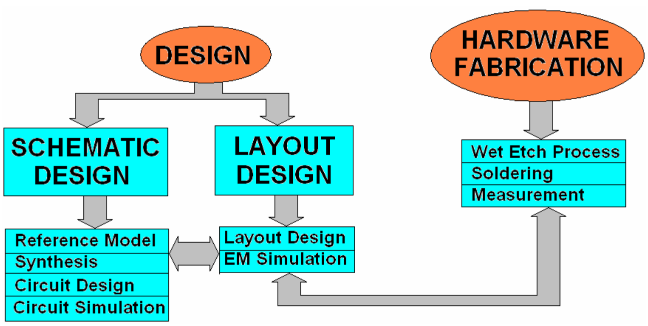

Figure 2: The Design and fabrication Workflow

For MoM, the design was done using CST Microwave studio and for circuit simulator the design was done using microwave office software. Analysis on simulation results have been made to get optimum results before proceeds to the fabrication process. The fabrication process was done on the FR-4 microstrip board with a dielectric constant (ε_r = 4.5), the thickness of substrate (h = 1.6 mm) and loss tangent (tan δ =0.019) using the wet etching technique.

Figure 3 shows the prototype of the DRA. The DRA is located on top of microstrip line. This method is attractive due to the low cost and eases of fabrication, since there is no requirement to etch both sides of the substrate, as required in the aperture coupling technique. The amount of coupling is depending on the permittivity of the dielectric, the higher the permittivity the higher the coupling. However, the higher permittivity of the dielectric material yields the lower bandwidth. The specification of the dielectric resonator is shown in Table 1.

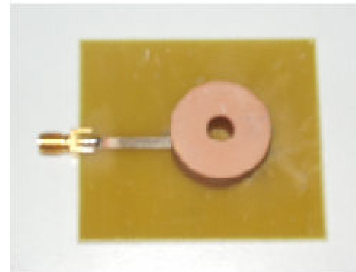

Figure 3: The disk shape of Dielectric Resonator antenna

Table 1: Data Of The Dielectric Resonator

Parameters	Values
Part Name	C8371-0945-438-262 Ceramic batch #QC1266470
Outer Diameter	24 mm
Inner Diameter	6.6 mm
Height	11.1 mm
Dielectric Constant	34.73
Frequency Approx.	2.415 GHz

An important parameter for DRA is its resonant frequency. The resonant frequency of the DRA is given by [7]:

$$f_r \approx \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{2\left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{2b}\right)^2}$$

(1)

Where:

- f_r : resonant frequency of TE_{mnp}- mode
- a : diameter of the dielectric resonator
- b : height of the dielectric resonator
- ε_r : permittivity of the dielectric
- c : velocity of light (≈3 X10^{8}m/s)

From equation (1) the resonance frequency of a dielectric resonator depends on the dimensions of the resonator and its dielectric constant. Therefore, the DRA size decreases as the dielectric constant increases.

Wavelength of the dielectric resonator is important because from this wavelength the dimensions of microstrip circuit can be designed. The equation of the wavelength is given by:

$$\lambda = \frac{c}{f_r\sqrt{\varepsilon_r}} \qquad (2)$$

The guided wave length has been calculated at frequency 2.4 GHz. The length is selected to ensure that the dielectric resonator will resonate upon excitation by a magnetic field. For simplification the frequency that has been applied from the input will resonate at the desired frequency. The length of microstrip line obtained from the calculation is 3 mm for the width and 28 mm for the length of the microstrip line.

The optimum distance between DR and microstrip line are determined by simulation and measurement. This is base on the trial and error approached. From the experimental work, the best distance obtained between DR and microstrip line is 4 mm as shown in Figure 4.

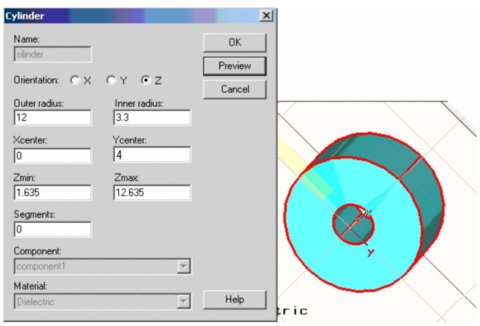

Figure 4: The distance between DR and microstrip line using CST software

The dielectric resonator antenna is a resonant circuit that is able to store electromagnetic fields with a minimum loss of energy within the resonator [2], i.e. a cavity with a high-unloaded quality factor, Q_U. By definition

$$Q_U = \frac{\text{total energy stored}}{\text{Energy dissipated per radian}}\Bigg|_{\text{at resonance}} \qquad (3)$$

This is the most general definition of Q. For the special case of a single resonance; Q becomes the reciprocal of the fractional bandwidth. The energy dissipation is internal to the composite resonator structure for Q_U calculations and may include contributions to the loss from the electric fields in the resonator and lossy substrate and the current flow in the ground plane. The external Q, Q_E is calculated in terms of energy dissipation external to composite resonator structure and is generally determined by all the coupling mechanisms from the feed lines into and out of the resonator. The loaded Q, , Q_L, takes into account all causes of energy dissipation and is given by

$$\frac{1}{Q_L} = \frac{1}{Q_U} + \frac{1}{Q_E} \qquad (4)$$

3. RESULT AND DISCUSSION

Figure 5 shows the comparison between simulation and measurement result. It shows that the simulation and measurement give the comparable result. The return loss for simulation is between -23 and -32 dB at frequency 2.4149 GHz. The measurement result gives the return loss of -19 dB at frequency 2.38 GHz. The bandwidth for simulation and measurement is between 110 MHz and 140 MHz. The frequency has been from measurement and simulation to the lower range of frequency. This will be explained in the end of the discussion.

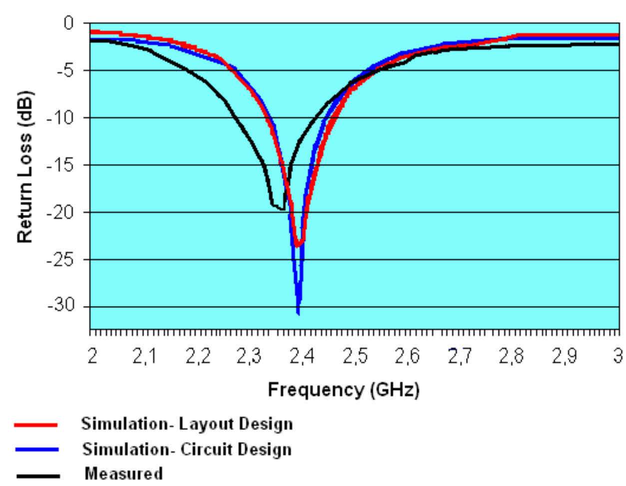

Figure 5: The graph between the simulation and measurement results.

Table 2: Simulated And Measured Return Loss And Bandwidth

Method / Parameter	Simulation		Measurement
	Layout design	Circuit design	
Frequency Resonant	2.4149GHz	2.4GHz	2.38GHz
Return Loss	-23.83dB	-32.6dB	-19.25dB
Bandwidth	119.9MHz	110MHz	140MHz
Percentage Bandwidth	4.962%	4.594%	5.915%

Table 2 shows the simulation and measurement results for return loss and bandwidth of DRA. The desired frequency resonant is at 2.4 GHz and the tolerance is between ± 0.2%. The simulation, measurement and calculation using the formula given in equation (1) are within the range of frequency resonant. A good antenna should indicate a return loss of less than -10 dB, which indicates that the antenna absorbs more than 90% of the fed power. The designated DRA is suitable for Wireless LAN IEEE 802.11b/g of Wireless LAN application since its bandwidth is within the range of the application.

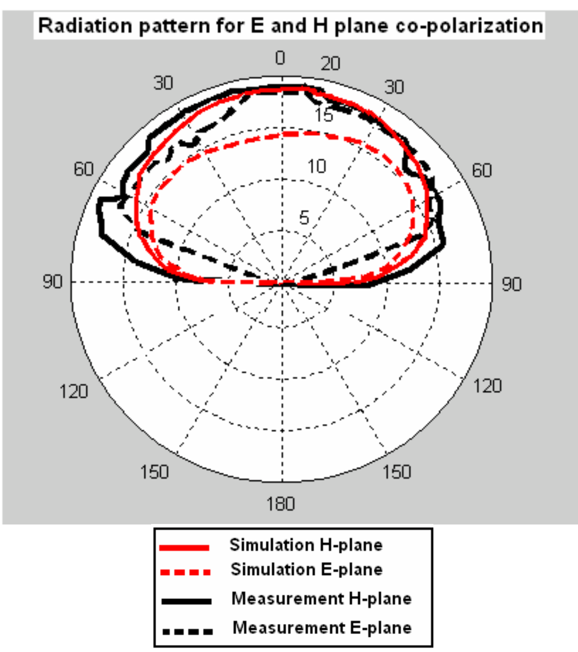

Figure 6: The combination results between simulation and measurement for radiations pattern for E and H-plane co-polarization.

Figure 6 shows the comparison between simulation and measurement result of the radiation patterns for E and H-plane. The HPBW for H-plane is 77.72^0 greater than measurement, which are 72^0. The HPBW for E-plane is 46.61^0 for measurement and 45^0 for simulation respectively.

It can be obtained that the measurement of the resonance frequency has been shifted to the lower frequency compared to the simulation. There are a few factors contribute to this effects. This is listed as below:

3.1 Adhesives for Dielectric Resonator

Adhesives will pull the DR frequency. It's possible for the frequency to go up or down, depending upon the mode, the adhesives' dielectric constant, and how the adhesive interacts with the E fields. The adhesive will behave as a thin spacer, with bond line that must be process-controlled, between the resonator and the support. This space is filled with a dielectric constant lower than the ceramic, and that effect must be verified experimentally.

3.2 Environment

Environment for the place that the measurement taken is one of the main factors affect the frequency shifted. Suppose the around the environment should be in vacuum so the better results because human, another equipment, win, and another environment fact can effect for the measurement results.

3.3 Equipment

Equipment used for measurement purpose should be in a good condition. All procedure for using the equipment must be followed and supervised by a person who expert in using the equipment or experience technician. The calibration must be done before started to use the equipment.

3.4 Fabrication process

Accuracy is vital in this stage, any minor mistake make an impact on the results. Proper fabrication must be considered while preparing the layout of DRA, etching process and cleanliness.

4. CONCLUSION

The ring disk DRA was successfully implemented. The desired frequency of interest is at 2.4 GHz, which is suitable for WLAN application. Although the fabricated antennas have shown small percentage of frequency shifted from the desired frequency, radiation performances of DRA are acceptable.

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