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Dielectric Resonator Antenna Design with High Gain and Wide Bandwidth

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Abstract: This study presents a design of dielectric resonator antenna with filtering capability at C-band. The antenna design consists of dielectric substrate on which a dielectric material with permittivity of 10 is designed to work as radiated element. A pair of separated aperture coupling slots are etched on the ground plane to couple the microstip feed line to the top dielectric material. Open stub with microstip feedline is designed for filtering function. The proposed antenna can achieve a wide bandwidth of 456.5 MHz in the range from 4.8911-5.3476 GHz. High order harmonic suppression and low order harmonic suppression are achieved which improve the antenna filtering response. The antenna can achieve a gain of 6.34 dBi, return loss <-25 dB and VSWR of 1.1 dB. The proposed dielectric resonator antenna has high performance with good filtering response which is useful feature in modern wireless communication systems.

Key words: Antenna and filter, bandwidth, communication system, gain, dielectric material, wireless communication systems

INTRODUCTION

Nowadays, with the fast development in wireless communication system, compacting the size and enhancing the performance become vital. One important part in wireless communication system is the front end (Tang *et al*., 2016; Alhegazi *et al*., 2016). The conventional design of the wireless communication system consists of an antenna and filter that separately designed (Mandal and Chen, 2010; Zuo *et al*., 2009; Troubat *et al*., 2007; Chuang *et al*., 2011). This design can collect and transmit signals in the desired band. However, the size is bulky and impractical. Many efforts on the integration of the antenna and filter into subsystem have been focused to reduce the size. The co-design of the antenna and filter can reduce the matching circuit between them which make more compact than the traditional filtering antennas. In (Chuang and Chung, 2011; Yusuf *et al*., 2011; Yusuf and Gong, 2011; Hsieh *et al*., 2015; Chen *et al*., 2013; Jiang and Werner, 2015) an antenna is used as the last-stage resonator of the filter which reduced the size by eliminating the matching circuit between the antenna and the filter. However, the insertion loss introduce by the filter degrades the antenna efficiency.

From previous research on filtering antenna, it can be noted that most the filtering antennas used metallic patch, horn antennas and slots to perform filtering function. Despite the advantages of Dielectric Resonator Antenna (DRA) such as wide bandwidth, small size and lightweight (Petosa, 2007), only few studies have used it. Furthermore, the losses with dielectric resonator antennas is very small as all the components in antenna are made of dielectrics that have very small loss compared to the metallic material.

In this study, a dielectric resonator antenna is designed with filtering function within the antenna itself to compact the size and enhance the performance. The proposed antenna can achieve a bandwidth of 456.5 MHz. The antenna has return loss of <-25 dB, gain of 6.34 dBi and Voltage Standing Wave Ratio (VSWR) of 1.1 dB. The antenna shows a good results which enable it to be applied in modern wireless applications.

MATERIALS AND METHODS

Antenna design: As show in Fig. 1, the proposed dielectric resonator antenna consists of two layers. Dielectric material with relative permittivity of 10 is

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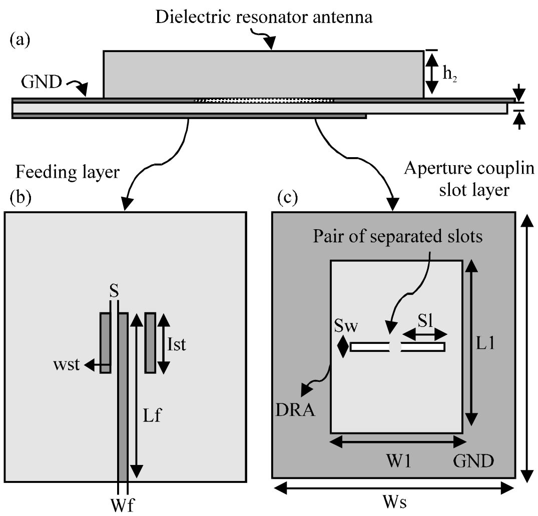

Fig. 1: The geometry of the proposed dielectric resonator antenna: a) Side view of the dielectric resonator antenna; b) Feeding network (bottom view) and c) Top view including the dimensions of aperture coupling of pair of separated slots

designed on the top layer of the antenna on a substrate with a thickness of 0.813 and 3.38 mm relative permittivity to work as radiated element. The feeding network that consists of single microstrip feedline with parallel stubs is designed in the bottom layer as show in Fig. 1b. The parallel stubs are used to perform filtering function and suppress higher order harmonics. A pair of separated slots are etched on the ground plane as shown in Fig. 1c. The separated slot is instead of continuous slot to provide harmonic suppression in lower frequency band. The resonance frequency of rectangular dielectric resonator antenna can be calculated (Balanis, 2005; Pozar and Targonski, 1991) using Eq. 1:

$$f_r = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m\pi}{a}\right)^2+\left(\frac{n\pi}{b}\right)^2+\left(\frac{p\pi}{d}\right)^2} \tag{1}$$

where, m, n, p are the variation on x, y and z axises, respectively of the half-wave field. The width and length of a 50 Ω feedline can be obtained (Balanis, 2005; Pozar and Targonski, 1991) using Eq. 2-5. For condition when W/h>2:

$$\frac{W}{h} = \frac{8e^A}{\left(e^{2A}-2\right)} \tag{2}$$

For condition when W/h<2:

$$\frac{W}{h} = \frac{2}{\pi}\left[B-1-\ln(2B-1)\right]+\frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1)+0.3-\left(\frac{0.61}{\varepsilon_r}\right)\right] \tag{3}$$

Table 1: Dimensions of dielectric resonator antenna

Parameters	Value (mm)
Ws	70
Ls	75
W1	28
L1	42
h1	0.8
h2	5.5
Lf	43
Wf	1.745
S	1
lst	14
wst	1.5
Sw	1
Sl	6

Where:

$$A = \left(\frac{Zo}{60}\right)\left[\frac{\varepsilon_r+1}{2}\right]^{\frac{1}{2}}+\left[\frac{\varepsilon_r-1}{(\varepsilon_r+1)\left(0.23+\left(\frac{0.11}{\varepsilon_r}\right)\right)}\right] \tag{4}$$

$$B = \frac{377\pi}{\left(2Zo\sqrt{\varepsilon_r}\right)} \tag{5}$$

All the parameters calculated and optimized in CST software are list as in Table 1.

RESULT AND DISCUSSION

The results of dielectric resonator antenna such as bandwidth, return loss, matching impedance, Voltage Standing Wave Ratio (VSWR), radiation pattern and gain are presented in this section.

Return loss: The filtering antenna is simulated on a wide range from 0-10 Ghz. The antenna resonates in the C-band practically from 4.8911-5.3476 GHz as shown in Fig. 2 the return loss is less than -25 dB at 5 GHz.

Matching impedance: The feeding network of the proposed dielectric resonator antenna is simulated with the parallel stubs to insure well impedance matching. The 50 impedance feedline is designed to be compatible with the practical coaxial cable. The impedance matching of the antenna is shown in Fig. 3.

Voltage wave standing ratio: The VSWR of the dielectric resonator antenna is simulated as shown in Fig. 4. It can be seen that the VSWR is around 1 dB in range from 4.9-5.3476 GHz which indicates a good matching in the desired frequency band.

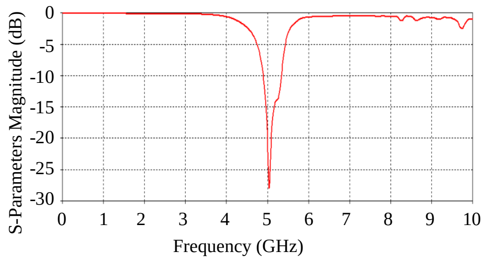

Fig. 2: Simulated return loss of the proposed dielectric resonator antenna

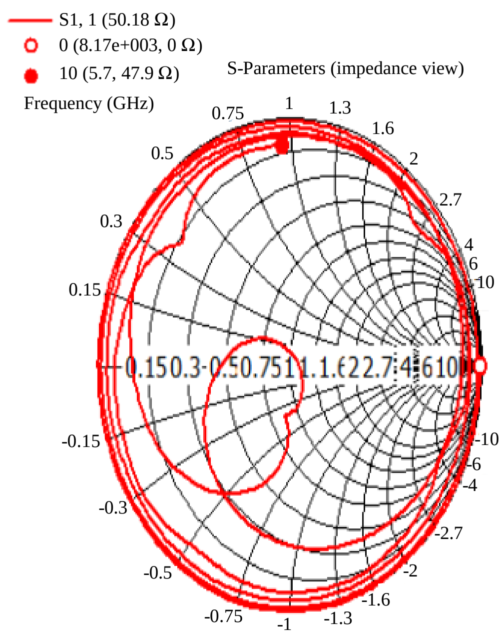

Fig. 3: Matching impedance of the antenna

Bandwidth: One of the dielectric resonator antennas is that it can provide a wide bandwidth. The bandwidth of the antenna is calculated below -10 dB from 4.8911-5.3476 GHz which resulted in 456.5 MHz as illustrated in Fig. 5.

Gain: The gain of dielectric resonator antenna is shown in Fig. 6a shows the antenna gain at 5 GHz while Fig. 6b shows the antenna gain at 5.2 GHz. The total efficiency can reaches -0.47 dB which is one of dielectric resonator advantage. The dielectric antennas suffer from low losses due to the use of dielectric material as radiated element instead of metallic material that normally contributed to the reduction of antenna efficiency.

Radiation pattern: The radiation pattern of the proposed dielectric resonator antenna is shown in Fig. 7. It can be noted that most the radiation is focused in toward 0 angle. The side lobe level is limited to -13.1 dB. Most of the power is radiated in main lobe. Thus, the proposed dielectric resonator antenna has the property of omnidirectional radiation.

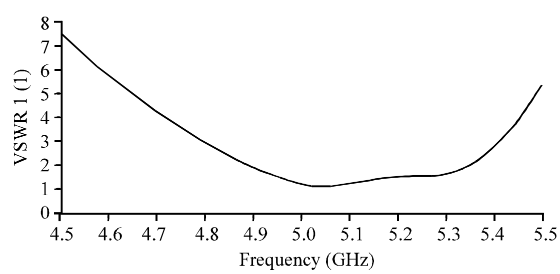

Fig. 4: Voltage standing wave ratio

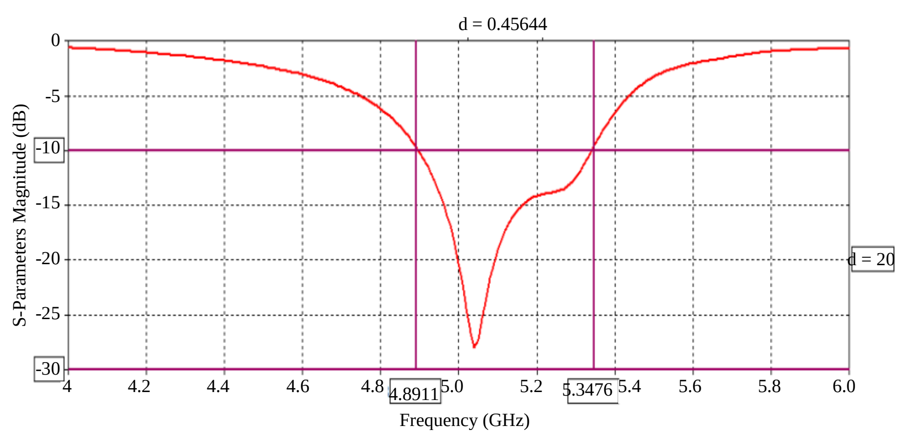

Fig. 5: Bandwidth of the dielectric resonator antenna

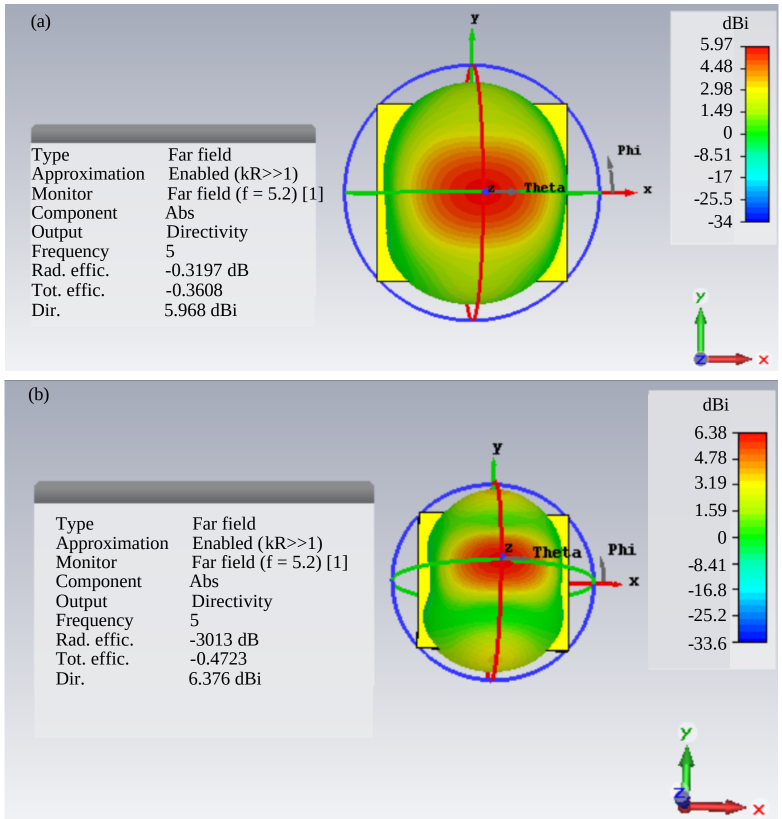

Fig. 6: Gain of dielectric resonator antenna: a) Gain of the antenna at 5 GHz and b) Gain of the antenna at 5.2 GHz

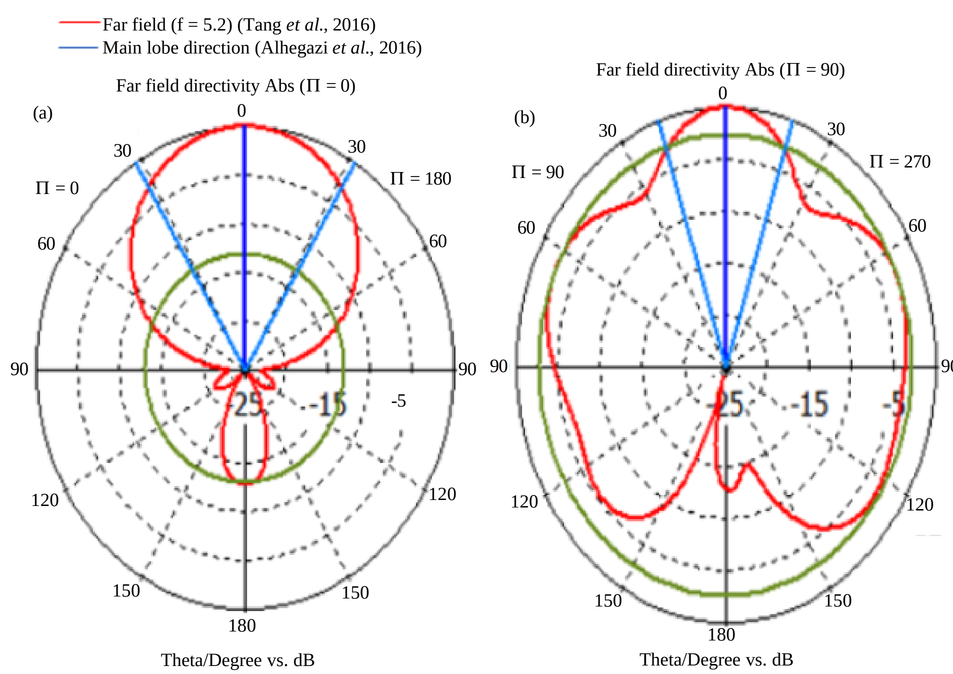

Fig. 7: Radiation pattern of dielectric resonator antenna: a) The radiation pattern at (π = 0) and b) The radiation pattern at (π = 90)

CONCLUSION

A dielectric resonator antenna with filtering property has been reported. This antenna can provide wide bandwidth of 456.5 MHz. The antenna shows a good results in terms of return loss, VSWR gain and radiation pattern. From results discussed, it can be noted that the antenna can be used for C-band applications such as radar system, satellite and WiFi.

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