CHAPTER – 4

Development of Multifrequency DRA

4.1 Introduction

The world of wireless communication has undergone an exponential growth in last few decades. Human civilization is now enriched with wireless communication technologies like GSM, Wi-Fi, Bluetooth, WLAN, WiMAX etc. The spectrum of electromagnetic waves is being used by all of these applications and hence there is a severe chance of interference resulting in distortion of various signals. In order to avoid this catastrophe and for an efficient and effective use of the available spectrum several international regulatory bodies like Federal Communications Commission (United States), Telecom Regulatory Authority of India (India), International Telecommunication Union (United Nations) have specified different bands of the available spectrum for specific applications. The free license nature of the ISM bands (Industrial, Scientific, Medical band) ranging from 2.4-2.484 GHz and 5.15-5.95 GHz has led to extensive use of these frequencies for wireless communications. Communications applications such as wireless sensor networks, wireless LANs, cordless phones etc. operates at 2.45GHz, and 5.8GHz bands. In order to use these bands effectively certain standards are declared by IEEE which are being followed throughout the world. According to IEEE802.11b standard frequency band from 2.4 to 2.484 GHz is allocated for WLAN. Band of IEEE802.11a covers 5 to 6 GHz range and are used for various wireless applications. With the advancement of technology there is an increasing trend of integrating different wireless systems which obviously calls for multiband antennas. Moreover if the antennas have discrete resonant frequency with narrow bandwidth then excellent frequency selectivity will be provided by the antenna itself thereby eliminating the requirement of bandpass filters. Keeping these issues in mind the author is presenting here a multiband or multifrequency antenna that covers the most popular ISM bands. The objective of the design is to obtain good performance in all the resonant frequencies. As a result, this single antenna can be used effectively at all resonant frequencies for various purposes. As it is found that
CPW feed has several advantages over the conventional probe or microstrip [1], a DRA with CPW feed is presented here. Inspired by many works in literature, where CPW fed slot coupled DRA have been designed [2-4] the author has designed a DRA with the same feeding technique retaining planar structure and integrability with any circuitry. Literature study reveals that though the number of antennas having dual resonances is good enough in number, but DRAs having triple resonances or more are very few. Moreover special techniques like stacked configuration, metal coating on top surface of the resonator block, special shapes or multiple DR blocks have been used in order to achieve multiple resonances [5-12]. In contrast to the adopted techniques the author tends to keep the design of the antenna extremely simple and compact. A single block of dielectric resonator is chosen having a very common shape of that of a cube. Multiple resonances in excess of four are expected to be the outcome of this design. Experimental investigations have also been carried out on the proposed multiresonant antenna in order to verify the simulated results.

The structure consists of a simple cubic dielectric resonator as shown in Fig 4.1. It is mounted on a CPW slot. The slot is designed to have a loop like structure to couple energy from the CPW to the DRA. The antenna design parameters like the dimensions of the DRA, the relative position of DRA with respect to the slot etc. are optimized through extensive simulation using the commercial software Ansoft HFSS [Ver.11] to obtain optimum performance in terms of gain and number of resonant frequencies.

Fig 4.1 Structure of the proposed antenna  Fig 4.2 Structure of the loop shaped slot
4.2 Antenna Design

The CPW feed is designed to excite a loop shaped slot (fig 4.2). It is fabricated on RT/Duroid substrate with dielectric constant \( \varepsilon_r \) 10.2 and thickness of 120 mils. The shape of the substrate is a perfect square with \( LS = WS = 140 \text{ mm} \) and it is without a back conductor. CPW with \( S=1.04 \text{ mm} \) and \( G =2.62 \text{ mm} \) is chosen to obtain an input impedance of 50\( \Omega \) where \( G \) is the central conductor and \( S \) is the gap. The length of the slot is carefully designed so that it remains fully covered by the DRA. The main objective of the design to obtain multiple resonant frequencies between 2 to 7 GHz using only a resonating slot and a single DRA block having common shape like rectangular parallelepiped.

The resonant frequency of the loop shaped radiating slot (Fig. 4.2) was chosen to be 2.5 GHz for which the calculated slot length (which should be equal to guided wavelength \( \lambda_g \)) obtained is approximately 31 mm. Initially a slot of this length is drawn over which a DRA of size \( a=18 \text{ mm}, b=15 \text{ mm} \) and \( c=20 \text{ mm} \) is placed as shown in Fig.4.1. The DRA consists of material with \( \varepsilon_r = 20 \) and is parallelepiped in structure. The dimensions are so chosen such that DRA has resonant frequency close to that of the slot as obtained from Marcatili’s Dielectric Waveguide Model. Initially the slot is placed centrally below the DRA to obtain maximum energy coupling with anticipation that higher order modes will be generated. Simulated results for \( S_{11} \) (reflection coefficient) is shown in Fig.4.3

![Fig. 4.3 Plot of \( S_{11} \) vs. frequency with initial slot and DR dimensions](image-url)
Three resonant frequencies are observed which indicated that initial design parameters are close to our goal. Next the slot length was increased to 34mm and the plot of $S_{11}$ vs. frequency obtained in this case is shown in Fig. 4.4. The result shows that the slot length is not good enough for our final goal. Moreover, matching was obtained at a frequency far away from the designed frequency.

![Fig. 4.4 Plot of $S_{11}$ vs. frequency with slot length equal to 34 mm and initial DR dimensions](image)

Significant improvement occurred when the slot length was increased to 37.2mm. The DRA was again placed centrally on the slot and the result obtained (shown in Fig. 4.5) indicates four resonant frequencies.

![Fig. 4.5 Plot of $S_{11}$ vs. frequency with slot length equal to 37.2 mm and initial DR dimensions](image)
It is seen that the dimensions of the slot chosen in the previous design gives good result. However in order to achieve more resonant frequencies the author now changes the dimensions of the DRA. It is well established that change in aspect ratio will change the fundamental resonant frequency and thereby may generate more higher order resonant frequencies. When the DRA of dimensions $a=18\text{mm}$, $b=18\text{mm}$ and $c=20\text{mm}$ was placed centrally on a slot of length $37.2\text{ mm}$ five resonant frequencies were observed as shown in Fig 4.6.

![Fig. 4.6 Plot of $S_{11}$ vs. frequency with final slot length and changed width of the DR](image)

As the number of resonant frequencies has increased with increase in size of the DRA the author choses to continue the trend. Satisfactory result was obtained when a DRA of cubic shape was chosen where each side of the DR block was $20\text{mm}$ in dimension. A total of six resonant frequencies were observed (Fig. 4.7). No simple structure like this producing six resonant frequencies was reported in open literature thus far. The position of the loop with respect to DRA was also adjusted to obtain optimum match at all the resonant frequencies.
The final design of the antenna is thus obtained through thorough parametric studies. The slot parameters are optimized through HFSS (ver.11) simulation. The final slot design is as follows: $U=4.46\,\text{mm}$, $V=7.33\,\text{mm}$, $L=13.62\,\text{mm}$ and $P=66.375\,\text{mm}$ (Fig. 4.2). Each side of the cubic DRA has a length of 20mm. The DRA is designed with $\varepsilon_r=20$. The final position of the DRA with respect to the loop is optimized using HFSS (ver.11) to achieve improved coupling. The center of the DRA is placed at an offset of 5.04 mm from the center of the loop along X axis. The best result which was obtained for $S_{11}$ is shown in Fig. 4.8. The fabricated slot and the proposed antenna are shown in Fig.4.9 and Fig.4.10 respectively.
4.3 Results

Simulated results have been obtained to observe the $S_{11}$, radiation patterns and gain characteristics of the proposed antenna. Measurements have been carried out with the fabricated antenna in order to validate the obtained simulated results.

a) $S_{11}$ Characteristics (simulated and measured)

The proposed antenna resonates at six different frequencies. All the resonant frequencies have $S_{11}$ well below -10db. Apart from the first resonant band all other resonant frequencies have narrow bandwidth which is a necessary criterion to have high selectivity and avoid out of band interference (crosstalk). It is observed that the first resonant band is wide enough and covers the first ISM band efficiently. Subsequent resonant bands are profusely separated from the first resonant bands. They are closely placed having very narrow bandwidth, cover second ISM band and thus can be used for multifrequency operation with excellent frequency selectivity characteristics. Measurement for $S_{11}$ has been done using a vector network analyzer (Model # 5071 B) from Agilent Technologies. The network analyzer is calibrated using the 2 port Ecal module, bearing model # 85092C for an operating frequency ranging from 1GHz to 10 GHz, which provides sufficient accuracy. The simulated and measured values of resonant frequencies are shown in Table 4.1. A very good match between simulated
and experimental values is observed from the table. The lack of agreement between simulated and measured results may be due to the air gap which is present between the ground plain and the DRA in the fabricated antenna. The plot of $S_{11}$ vs. frequency is shown in Fig. 4.11. Six different resonant frequencies are observed between 2 to 7GHz which are circled in the diagram. The percentage of error between the simulated and measured values are 2.18\%, 3.83\%, 0.74\%, 2.27\%, 2.63\% and 1.91\% at 2.34GHz, 4.51GHz, 5.32GHz, 5.58GHz, 5.91GHz and 6.4GHz respectively.

**Table 4.1**

<table>
<thead>
<tr>
<th>Freq(GHz)</th>
<th>Freq(GHz)</th>
<th>Percentage of Error</th>
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<tr>
<td>Simulated</td>
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</tr>
<tr>
<td>6.4</td>
<td>6.28</td>
<td>1.91</td>
</tr>
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</table>
Fig 4.11 Simulated and Experimental plot of $S_{11}$ vs. frequency of the hybrid antenna (Proposed)

To explain the hybrid nature the $S_{11}$ and impedance characteristics are studied for only slot (Fig.4.12 and Fig.4.13) and DRA (Fig.4.14 and Fig.4.15) separately. Impedance characteristic of the final hybrid structure is also investigated (Fig. 4.16).

Fig.4.12 Plot of $S_{11}$ vs. frequency for only slot

Fig.4.13 Plot of impedance vs. frequency for only slot
It is observed that although slot, as an individual radiator, does not show good impedance match within our frequency range of interest but resonates many times within 1-7 GHz. Many of these resonant frequencies match perfectly with resonant bands of our final result (Fig. 4.11).

On the other hand when the DRA was studied separately it showed exceptional good impedance match within our frequency range of interest (Fig. 4.14). Moreover resonance is also observed at various frequencies which match quite well with our final result (Fig. 4.15).

Fig. 4.14 Plot of $S_{11}$ vs. frequency for only DRA

Fig. 4.15 Plot of impedance vs. frequency for only DRA

Fig. 4.16 Plot of impedance vs. frequency of the hybrid antenna (Proposed)
When impedance characteristics of the hybrid antenna is studied we find good impedance match for both real and imaginary parts (encircled in Fig.4.16) at the resonant bands finally obtained as shown in Fig. 4.11.

b) **Gain (simulated and measured)**

Gain at all the resonant bands have been obtained through simulation and have been verified experimentally. Gain-comparison method [13] has been used to measure the gain of the fabricated antenna at all the six resonant frequencies. Simulated gain of the proposed antenna at 2.34GHz, 4.51GHz, 5.32GHz, 5.58GHz, 5.91GHz and 6.4GHz are 4.91db, 6.98db, 2.7db, -3db, 5.6db, -5.6db respectively, whereas the measured values are 6db, 8db, 4.1db, -4db, 6.3db and -7db respectively. All the simulated and measured values are in good agreement with each other. The values of simulated gain and measured gain are tabulated in Table 4.2.

It is also observed from Table 4.2 that gain at frequencies 5.58GHz and 6.4GHz is negative. This occurs due to poor coupling between DRA and slot which is further augmented by the spurious radiation from the feed network as seen from Fig. 4.17 (a), (b) and Fig. 4.18 (a), (b).

<table>
<thead>
<tr>
<th>Freq(GHz)</th>
<th>Freq(GHz)</th>
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<th>Gain(db)</th>
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<tbody>
<tr>
<td>Simulated</td>
<td>Measured</td>
<td>Simulated</td>
<td>Measured</td>
</tr>
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<td>6.4</td>
<td>6.28</td>
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Table 4.2

*Simulated and Measured Gain at Resonant Frequencies*
Fig. 4.17(a) Plot of current distribution at the bottom of DRA at 5.58 GHz

Fig. 4.17 (b) Plot of current distribution along the slot with DRA at 5.58GHz
Fig. 4.18(a) Plot of current distribution at the bottom of DRA at 6.4 GHz

Fig. 4.18 (b) Plot of current distribution along the slot with DRA at 6.4 GHz

c) Radiation patterns (simulated and measured)

The radiation patterns have been studied for all the six resonant frequencies. Both co-polar and cross-polar patterns for E plane (x-z plane at $\varphi=0$) and H plane (y-z plane at $\varphi=\pi/2$) are studied. The radiation patterns suggest that the antenna radiates in the broadside directions. Measurement of radiation patterns have also been done for all the resonant six frequencies. Here also we find good match between the simulated and measured patterns. Fig. 4.19 (a) – 4.19 (f) shows the simulated and measured radiation patterns at all the six resonant frequencies.
Fig. 4.19(a) Radiation patterns at 2.29 GHz

Fig. 4.19(b) Radiation patterns at 4.69 GHz

Fig. 4.19(c) Radiation patterns at 5.36 GHz
Fig. 4.19(d) Radiation patterns at 5.71 GHz

Fig. 4.19(e) Radiation patterns at 6.07 GHz

Fig. 4.19(f) Radiation patterns at 6.28 GHz.
4.4. Summary

A very simple but useful hybrid multifrequency antenna is proposed. The antenna consists of a cubic DRA coupled with a resonating slot. The proposed antenna is compact in size and simple in configuration. Six different resonant frequencies are observed with satisfactory gain in almost all the frequencies. Both E and H plane co-polar and cross-polar radiation patterns are excellent in nature. The proposed antenna can be used for multiple purposes. The 2GHz range can be used for wireless communication. The Federal 4 GHz spectrum spans from 4.4 GHz to 4.99 GHz. This spectrum is allotted in the U.S. and NATO countries for military fixed and mobile communications. Typical uses include point-to-point microwave, drone vehicle control and telemetry. Moreover the 4.5 GHz frequency can be used for satellite communication in array environment also. The 5GHz frequency range can be used for 5.15–5.825 GHz (IEEE 802.11a) WLAN. This antenna can also have biomedical or imaging applications at frequencies with negative gain. Moreover the multifrequency antenna can be used for any wireless communication where more than one band is required to transmit or receive signal.

References


