Chapter 4

Ring-Shaped DGS to Reduce Mutual Coupling between Microstrip Antennas
4.1 INTRODUCTION

In previous chapter, we explored the application of a ring shaped DGS to reduce mutual coupling between two adjacent cylindrical DRAs. Other than DRAs, microstrip patch antennas are also used in array configurations to achieve high gain, beam steering properties [1] – [5]. Mutual coupling between patch elements is also a serious issue [2], [6]-[9], especially when multiple elements are closely packed, e.g., in MIMO systems [10]. Both experimental [11], [12] and analytical methods like transmission line model [13], cavity model, method of moment [6] have been used to study mutual coupling between microstrip antenna elements. Mutual coupling distorts radiation pattern, introduces scan blindness and degrades the performance. Scan blindness was studied for printed dipoles and rectangular patches in [14]-[16]. These arrays share the same substrate and mutual coupling between elements occur due to surface waves [3], [17]. Different approaches have been reported in literatures [18]-[25] to resolve this problem of mutual coupling in microstrip arrays. Amongst those techniques, micro-machined substrate [18], electromagnetic band-gap [19]-[23], and soft surfaces [24] indicate 5–10 dB suppression in coupling parameter.

Electromagnetic band gap (EBG) materials are used between microstrip antenna elements with stop-band around its operating frequency, which prevents EM waves from propagating through the substrate. This is also established from the studies in chapter 3, that stop-band property of a DGS is also capable of reducing mutual coupling between two DRA elements.

In this chapter, we have explored a single ring-DGS to control mutual coupling values between two adjacent microstrip patches. The design is similar to that in Chapter 3, although the basic radiating elements along with their operating frequency are different. Nearly 4 dB reduction in mutual coupling has been demonstrated. Another important feature of suppressed cross-polarized radiation has also been documented.

4.2 THE STRUCTURE

Two element E-plane coupled microstrip patch with and without DGS is described below. The design procedure of the ring DGS has been explained and the performance of DGS-integrated patch is studied.
4.2.1 Microstrip Patch Antenna with Normal Ground Plane

To study DGS integrated array of microstrip patch antenna we begin by choosing patch geometry and its operating frequency. To maintain symmetry with the ring DGS we have chosen a circular probe fed microstrip patch antenna as shown in Fig. 4.1. The dimension of the patch, i.e. radius $a$, is calculated using formulas in [26] to operate near 10 GHz. Calculated radius of the patch $a = 5$ mm for a PTFE substrate with thickness $t = 1.575$ mm and dielectric constant $\varepsilon_r = 2.3$. Matched location for the probe ‘f’, shown in Fig. 4.1, is optimized using simulated results [27]. Simulated $S_{11}$ of the patch with
Fig. 4.2. Simulated $S_{11}$ versus frequency of the circular microstrip patch shown in Fig. 4.1 with varying probe location $f$. Other parameters as in Fig. 4.1.

Fig. 4.3. Schematic diagram of two E-plane coupled probe fed circular microstrip patch antenna on a PTFE substrate (a) top-view; (b) cross-sectional view. Parameters $a = 5$ mm, $f = 1.9$ mm, $D = 15$ mm ($0.5\lambda_0$), $t = 1.575$ mm, $\varepsilon_r = 2.3$. 
varying probe location is shown in Fig. 4.2. It is observed that proper matching is obtained with $f = 1.9 \text{ mm} (= 0.38a)$, where the patch resonates around 10.26 GHz.

A pair of probe-fed E-plane coupled circular microstrips is shown in Fig. 4.3. They are separated by $0.5\lambda_0$ (center-to-center distance is 15 mm for $f_0 = 10 \text{ GHz}$). EM simulations [27] were performed on the structure and resulting S-parameters are shown in Fig. 4.4. Maximum coupling ($S_{22}$ at about $-16.5 \text{ dB}$) occurs around the operating frequency.

4.2.2 Microstrip Patch Antenna with DGS

The procedure for designing a ring DGS to reduce coupling between two adjacent microstrip elements is similar to that described for DRAs in chapter 3. The ring DGS is placed mid-way between the two patches maintaining equal distance from the edge of each element. The DGS is concentric with one of the patches. Fig. 4.5 shows bottom and cross-sectional view of the array integrated with DGS. Like chapter 3, the DGS is characterized by its inner radius $r_s$, outer radius $r_o$, width $s$, and mean radius.
Fig. 4.5. Schematic diagram of two E-plane coupled probe fed circular microstrip patch antenna integrated with ring DGS (a) bottom-view; (b) cross-sectional view. Parameters: \( a = 5 \text{ mm}, f = 1.9 \text{ mm}, D = 15 \text{ mm} \left( 0.5\lambda_0 \right), r_m = 7.5 \text{ mm}, r_1 = 7 \text{ mm}, r_0 = 8 \text{ mm}, s = 1 \text{ mm}, t = 1.575 \text{ mm}, \varepsilon_r = 2.3. \)

\[ r_m = (r_1 + r_0)/2. \]  
Choice of \( r_m = D/2 \) places the DGS midway between the two patches separated by a distance \( D \). The width \( s \) of the ring is altered to produce a stop-band around the operating frequency. Determination of the width \( s \) is described below.

Figure 4.6(a) shows a 50\( \Omega \) microstrip line integrated with a ring DGS \( (r_m = 7.5 \text{ mm} = D/2) \). Simulated \( S_{21} \) for varying \( s \) value is studied in Fig. 4.6(b). A DGS with \( s = 0.5 \text{ mm} \) appears to be a good choice to produce stop-band around 10.25 GHz. These design parameters have been implemented in antenna configuration as shown in Fig. 4.5. This is further optimized using simulated data as studied in Fig. 4.7.
Fig. 4.6. (a) Single ring shaped DGS integrated with 50Ω microstrip line on a PTFE substrate with thickness $t = 1.575$ mm and dielectric constant $\varepsilon_r = 2.3$. Parameters: $w_i = 4.9$ mm, and $r_m = 7.5$ mm; (b) Simulated $S_{21}$ versus frequency of 50Ω microstrip line (Fig. 4.6(a)) with varying ring width $s$ and $r_m = 7.5$ mm.
Fig. 4.7. Simulated $S_{21}$ versus frequency of two element microstrip patch array integrated with single ring DGS (Fig. 4.5) with varying width $s$ and $r_m = 7.5$ mm. Other parameters as in Fig. 4.5.

Fig. 4.8. Simulated $S_{11}$, $S_{22}$ versus frequency of two probe fed E-plane coupled microstrip patch shown in Fig. 4.5. Parameters as in Fig. 4.5.
Different $s$ values including no DGS have been considered for a comparative study. 4-5 dB reduction in $S_{21}$ value is observed for $s = 1$ mm. Figure 4.8 studies the nature of reflection coefficients ($S_{11}$ or $S_{22}$) for each patch with and without DGS. No DGS configuration results in almost identical $S_{11}$ as indicated in Fig. 4.4 and as such single dotted curve is presented in Fig 4.8. Presence of DGS around patch #1 loads the patch inductively and causes slight right shift in resonance frequency. The effect of DGS on
patch #2 is negligible and shows no considerable change in resonance. Figure 4.9 portrays simulated electric fields in the substrate indicating their mutual sharing between two adjacent patches with and without DGS. The figure is self-explanatory and clearly shows weaker coupling when the DGS is present.
4.3 Experimental Results

A prototype was fabricated using Taconic substrate, which is shown in Fig. 4.10. The back side view in Fig. 4.10(a) clearly shows the ring DGS along with the SMA connectors used to feed the patches. Figure 4.10(b) shows the front side view of the prototype connected to the ports of Agilent's E8363B network analyzer. A prototype with normal ground plane was also fabricated for comparing measured results. Figure 4.11 shows measured $S_{21}$ values around resonance with and without DGS. The simulated results [27] are also compared with the respective measurements. Considerable suppression in $S_{21}$ value as indicated by the simulated data is closely supported by the measurements. About 4-5 dB reduction around the operating frequency has been experimentally obtained. Measured $S_{11}$ characteristics are compared with the simulated values in Fig. 4.12. Measured $S_{11}$ and $S_{22}$ curves are found to be shifted to the right compared to their simulated graphs. This may be attributed to the dimension of the fabricated antenna which is too sensitive in controlling the resonant frequency.

Figure 4.13 compares the measured radiation characteristics of the patches with and without defect. Each antenna has been measured with the other element terminated with matched load. The co-polarized patterns are found to be identical in both the principal planes over about ±120°. Beyond that, the defect causes excess radiation, although it remains at least 15 dB below the peak value. The measured peak gain was recorded as about 5.2 dBi. Apparently, the effect of the DGS is more pronounced in the E-plane, where the primary reason is the feeding probe located very close to a part of the defect and leaking through it. The DGS indicates a significant suppression of cross-polarized radiation in H-plane particularly and it varies from 5 to 20 dB. A detailed study of controlling cross-polarized radiations from a microstrip patch using DGS is presented in [28], [29].
Fig. 4.11. Measured and simulated $S_{21}$ versus frequency of two probe fed E-plane coupled microstrip patch shown in Fig. 4.10 with and without DGS. Parameters as in Fig. 4.5.

Fig. 4.12. Measured and simulated $S_{11}$ and $S_{22}$ versus frequency of two probe fed E-plane coupled microstrip patch shown in Fig. 4.10 with and without DGS. Parameters as in Fig. 4.5.
Fig. 4.13. Measured radiation pattern of the prototype shown in Fig. 4.10 (a) E-plane; (b) H-plane. Parameters as in Fig. 4.5.
4.4 CONCLUSION

Single ring shaped DCS is technically convenient to be accommodated in between two microstrip elements. A centrally located single ring can serve for as much as five elements: three in E-plane and three in H-plane. The DGS also indicates 1-2 dB reduction in H-plane coupling.

REFERENCES


[27] High frequency structure simulator (HFSS), Ansoft, v 11.1.
