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Study on Effect of Defective Ground Structure on Hybrid Microstrip Array Antenna

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Abstract This paper presents a novel study on effect of rectangular shape defective ground structure (DGS) implemented on two, four and eight element hybrid microstrip array antenna. The proposed antennas are designed using low cost glass epoxy material. The bandwidth and radiation performance of the antenna is studied and found that as the elements of the antenna are increased, bandwidth also increases by retaining almost the same radiation pattern and gain. Experimentally measured results and design concepts are presented and discussed. These antennas may find application in modern communication system, in radar systems like SAR, monopulse tracking radar and C, X and Ku band microwave applications.

Keywords: *DGS, microstrip array antenna, SAR, HPBW, gain, bandwidth*

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1. Introduction

Wireless communication has been developed widely and rapidly in the modern world during last decades. The future development of the personal communication device will aim to provide image, speech and data communication at anytime and anywhere around the world. So, present time is witnessing a very rapid growth of wireless technology. To increase access, communication terminals must meet the requirements of multi-band or wide band to sufficiently cover the possible operating bands and for broader connectivity. Wireless technologies has also revolutionized in the field of information technology by making use of high speed internet and data transfer 'wire free' via mobile gadgets. The existing wireless systems need the antenna structure to cover the various applications with fewer or preferably with a singe antenna.

In satellite and radar communication applications, microstrip antennas have attracted much interest due to their small size, light weight, low cost on mass production, low profile and easy integration with other components. However one difficulty in using microstrip patch antennas is their narrower bandwidth compared to that of other microwave antennas. In general, regular shape patch antennas have been extensively analyzed but these antennas cannot be applied in every application. In addition, simple patch antenna geometries of regular shape in general, resonate only at a single frequency and their bandwidth is also very poor (2 to 3 %). With the recent advancements in satellite and radar communications, the demand for broad band and multi band patch antennas was realized. Looking at inherent properties of patch antennas, these requirements forced workers for modification in patch antenna geometries. For this reason in recent years, there has been a great deal of research on ways to overcome the bandwidth problem of microstrip patch antenna. In application in which increased bandwidth is needed for operation of two or more separate sub-bands, a valid alternative to broadening of the total bandwidth is the use of dual or multi-frequency microstrip antennas [1].

The other disadvantage is the excitation of surface waves that occurs in the substrate layer. Surface waves are undesired because when a patch antenna radiates, a portion of total available radiated power becomes trapped along the surface of the substrate. It can extract total available power for radiation to space wave. Therefore, surface wave can reduce the antenna efficiency, gain and bandwidth. For arrays, surface waves have a significant impact on the mutual coupling between array elements [2].

Recently introduction of EBG and defective ground structure (DGS) made a significant break-through in the improvement of microstrip antennas characteristics. DGS is realized by etching the ground plane of microstrip antenna, this disturbs the shield current distribution in the ground plane which influences the input impedance and current flow of the antenna. The geometry of DGS can be one or few etched structures which are simpler and do not need a large area to implement it.

Many shapes of DGS slot have been studied for single element microstrip antenna such as circle, dumbbells and spiral. For two, four and eight element rectangular array a rectangular DGS is studied [3], however not many have realized it in hybrid antenna arrays.

This paper discusses the influence of rectangle shape DGS towards the improvement of impedance bandwidth and radiation properties. By adding the DGS, the surface wave propagation in the dielectric layer is suppressed,

resulting into enhancement in impedance bandwidth by retaining almost the same radiation pattern and gain.

2. Antenna Configuration

The proposed antennas are designed using low cost glass epoxy material having dielectric constant ϵ_r = 4.2 and thickness h = 0.166 cm. The geometry of two element hybrid microstrip array antenna with rectangle shape DGS (THMAA) is shown in Figure 1.

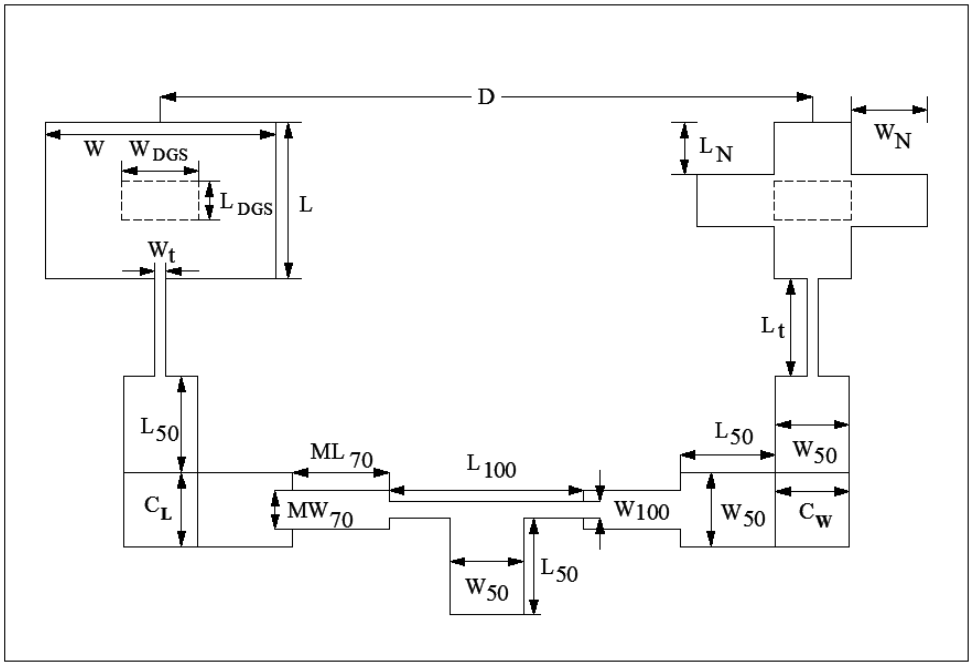

Figure 1. Geometry of THMAA

The elements of THMAA is designed for the resonant frequency of 9.4 GHz with dimensions

$$L = \left[\frac{C}{2 f_r (\varepsilon_e)^{\frac{1}{2}}}\right] - 2\Delta l \quad (1)$$

where,

$$\Delta l = 0.412\, h \left[\frac{(\varepsilon_e + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_e - 0.258)\left(\frac{W}{h} + 0.8\right)}\right] \quad (2)$$

$$\varepsilon_e = \left[\frac{(\varepsilon_r + 1)}{2}\right] + \left[\frac{(\varepsilon_r + 1)}{2}\right]\left[\frac{1 + 12h}{W}\right]^{-\frac{1}{2}} \quad (3)$$

and

$$W = \left[\frac{C}{2 f_r}\right]\left[\frac{(\varepsilon_r + 1)}{2}\right]^{-\frac{1}{2}} \quad (4)$$

After analysis, L = 0.66 cm and W = 0.99cm.

The elements of this array antenna are excited through simple corporate feed arrangement. This feed arrangement consist of matching transformer, quarter wave transformer, coupler and power divider for better impedance matching between feed and radiating elements. The microstripline feed is designed by using the *W/d* ratio equation taking the known value of characteristic impedance Z_0 and dielectric constant of substrate material ε_r. The design equations are,

$$W/d = \left[\frac{C}{2 f_r (\varepsilon_e)^{\frac{1}{2}}}\right] \text{ for } W/d < 2 \quad (5)$$

$$W/d = \left(\frac{2}{\pi}\right)\left[B - 1 - \ln(2B - 1) + \right]\left(\frac{\varepsilon_r - 1}{2\varepsilon_r}\right) \left\{\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\} \text{ for } W/d > 2 \quad (6)$$

where

$$A = \left(\frac{Z_0}{60}\right)\sqrt{\left[\frac{\varepsilon_r + 1}{2}\right]} + \left[\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right]\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \quad (7)$$

and

$$B = \left[\frac{377\pi}{2 Z_0 \sqrt{\varepsilon_r}}\right] \quad (8)$$

The length of microstripline is obtained from effective guide wavelength λ_g. It is given by,

$$l_g = \left[\frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}\right] \quad (9)$$

where

$$\varepsilon_{eff} = \varepsilon_r - \left[\frac{\varepsilon_r - \varepsilon_e}{1 + G\left(\frac{f}{f_p}\right)^2}\right] \quad (10)$$

$$G = \left(\frac{Z_0 - 5}{60}\right)^{\frac{1}{2}} + 0.004Z_0 \quad (11)$$

$$f_p = \frac{Z_0}{2\mu_0 h} \quad (12)$$

$$\mu_0 = 4\pi \text{ x } 10^{-9} \quad (13)$$

and

$$\lambda_0 = \frac{C}{f_r} \quad (14)$$

The length of microstripline feed $L_f = \lambda_g/4$cm is taken in order to keep minimum loss in microstrip line feed.

A two-way power divider made up of 70Ω matching transformer of dimension ML_{70} = 0.41, MW_{70} = 0.16cm is used between 100Ω microstrip line of dimension L_{100} = 0.83, W_{100} = 0.07cm and 50Ω microstrip line of dimension L_{50} = 0.41, W_{50} = 0.31cm. The equations used for designing two-way power divider are,

$$Z_1 = \frac{Z_2 \times Z_3}{(Z_2 \times Z_3)} \quad (15)$$

$$P_2 = \frac{\left(\frac{Z_1}{Z_2}\right)}{P_1} \quad (16)$$

and

$$P_3 = \left(\frac{Z_1}{Z_3}\right) P_1 \quad (17)$$

A coupler of dimension C_L = C_W = 0.31 cm is used between 50Ω microstrip lines to couple the power. The 50Ω microstrip line is connected at the center of the driven element through a quarter wave transformer of dimension L_t = 0.41, W_t = 0.04 cm for better impedance matching. The impedance of quarter wave transformer is given by

$$Z_t = \sqrt{(R_{in} Z_0)} \quad (18)$$

A notch is inserted at the four corners of last radiating element. The dimensions of notch length L_N and width W_N are taken in terms of λ_0. The L_N and W_N are optimized to $\lambda_0/14$ (0.22 cm) and $\lambda_0/10$ (0.33 cm) respectively. This optimized notch is selected, as it is more effective in enhancing the impedance bandwidth.

A rectangular DGS is embedded exactly below all the radiating elements. The dimensions of DGS of length L_{DGS} and width W_{DGS} are taken in terms of λ_0. The L_{DGS} and W_{DGS} of the DGS are optimized to $\lambda_0/13$ (0.0119 cm) and $\lambda_0/26$ (0.0255 cm) respectively. This optimized DGS is selected, as it is more effective in enhancing the impedance bandwidth [4].

At the tip of microstrip line feed of 50Ω, a coaxial SMA connector is used for feeding the microwave power. The array elements are kept at a distance of (D = 2.79) cm from their center point. This optimized distance is selected in order to add the radiated power in free space [5]. Further the study is carried out for four element hybrid microstrip array antenna with rectangular DGS (FHMAA) and eight element hybrid microstrip array antenna (EHMAA).

3. Experimental Results

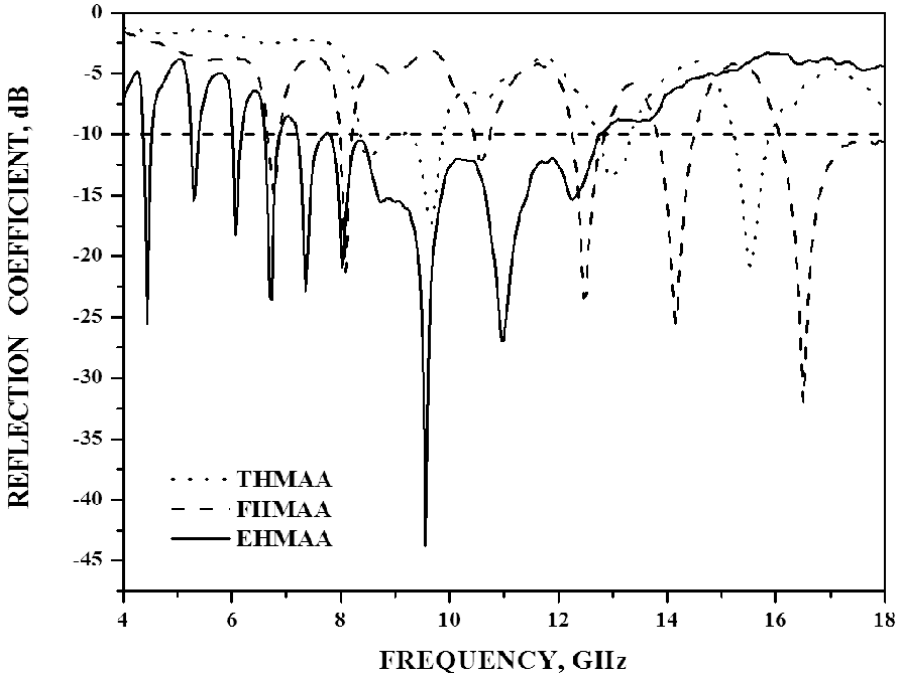

Figure 2. Variation of reflection coefficient versus frequency of THMAA, FHMAA and EHMAA

The impedance bandwidths for the proposed antennas are measured at 4 to 18 GHz frequencies. The measurements are taken on Vector Network Analyzer (Rohde & Schwarz, German make ZVK Model No. 1127.8651). The variation of reflection coefficient versus frequency of THMAA, FHMAA and EHMAA are shown in Figure 2.

The impedance bandwidth is calculated by using the equation

$$BW = \left[\frac{f_H - f_L}{f_C} \right] \times 100\% \qquad (19)$$

where, f_H and f_L are the higher and lower cut-off frequencies of the band respectively, when its reflection coefficient becomes -10 dB and f_c is the center frequency of band.

The experimental impedance bandwidth in term of MHz, percentage and reflection coefficient of all the proposed antennas is tabulated in Table 1.

The X-Y plane co-polar and cross-polar radiation patterns of all the proposed antennas are measured at their resonating frequencies and found that all the antennas show broad side radiation characteristics. Measured side lobe levels, cross polarization levels are tabulated in Table 1. The half power beam width (HPBW) and gain for the proposed antennas is calculated for their resonating frequencies and are also shown in Table 1.

In order to calculate the gain, the power received (P_s) by the pyramidal horn antenna and the power received (P_t) by the antenna under test are measured independently [5]. With the help of experimental data, the gain of antenna under test (G_T) in dB is calculated using the formula,

$$(G_T)_{dB} = (G_s)_{dB} + 10 \log (P_t / P_s) \qquad (20)$$

where, G_s is the gain of pyramidal horn antenna.

Table 1. Measured and calculated antenna parameters of THMAA, FHMAA and EHMAA

Antenna	Resonating Frequency, GHz	Band width MHz (%)	Reflection Coefficient, dB	Side lobe Levels	Cross Polarization Levels, dB	HPBW, deg	Gain, dB
THMAA	9.67	1510 (16.54)	-17.34	----	-5	51	12.96
	12.96	630 (4.83)	-13.73	----	-4.5	Split beam	----
	15.55	670 (4.30)	-20.90	----	-3	65	7.72
FHMAA	6.76	201 (3.10)	-14.90	-3.5	-7	30	9.40
	8.09	210 (2.59)	-21.38	-4	-5	30	6.40
	10.58	310 (2.93)	-12.11	-10	-14.5	12	9.66
	12.47	590 (4.70)	-23.48	-13.5	-6	Split beam	----
	14.15	700 (4.95)	-25.53	-5.	-11	25	12.48
	16.49	1960 (11.51)	-31.95	----	-3.5	Split beam	----
EHMAA	4.45	140 (3.14)	-25.59	----	-7	Split beam	----
	5.29	140 (2.62)	-15.43	----	-5.5	Split beam	----
	6.06	140 (2.29)	-18.25	-6	-12	8	8
	6.73	250 (3.70)	-23.62	-5	-8	8	8
	9.56	5670 (56.61)	-43.78	-4.5	-7	44	4.25

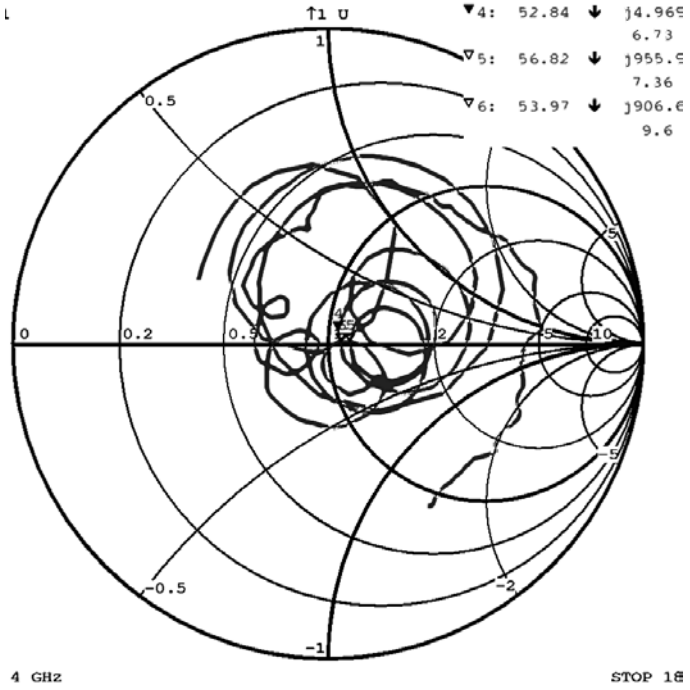

Figure 3 Input impedance profile of EHMAA

From the table it is observed that the proposed antennas are resonating for wide band and multiple frequencies. The multi frequency operation of the antenna may find application in modern radars where the system requires operating at more than one frequency bands. Multi frequency patch antennas may avoid the use of different antennas for each operating band, a typical case is that of Syntactic Aperture Radar (SAR). This would reduce weight and surface area, thus improving the possibilities of accommodation under the launcher fairing [6]. The proposed antennas may also be used for X band radar applications [7]. These antennas can also be used in UWB application and for C and X band microwave applications where limited antenna real estate is available. Further

from Table 1, it is observed that the antenna FHMAA can be used for X band monopulse tracking radar [8]

The variation of input impedance of EHMAA is shown in Figure 3. It is seen that the input impedance has multiple loops at the center of Smith chart that validates its wide band and multiple frequency operation.

4. Conclusion

A new DGS geometry, the rectangle shape have been used for two, four and eight element rectangular microstrip antenna array. The results demonstrate that impedance bandwidth of the antenna is improved by increasing the array elements with DGS. These antennas are more superior as these are fabricated using low cost substrate material. These multi-frequency patch antennas may provide an alternative to large bandwidth planar antennas, in applications in which large bandwidths are needed for operating at two separate transmit-receiver bands. When the two operating frequencies are far apart, a multi-frequency patch structure can be conceived to avoid the use of separate antennas. These antennas are more suitable for modern communication systems and in radar systems like SAR for tracking the target as soon as finding them and for anti-jamming. Further these antennas can be used for X band radar applications, UWB application, for C and X band microwave applications where limited antenna real estate is available and the antenna FHMAA can be used for X band monopulse tracking radar.

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