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Full Length Article

Analysis of low mutual coupling compact multi-band microstrip patch antenna and its array using defected ground structure

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In this paper, a simple microstrip patch antenna and a two-element E-plane coupled microstrip antenna array employing a defected ground structure are investigated. Without defected ground structure, the antenna has an impedance bandwidth of 675 MHz (6.78% at the center frequency of 9.955 GHz) and a gain of around 4.38 dB. The performance of the microstrip antenna in terms of impedance bandwidth, matching performance, gain and return loss can be improved by introducing a defect in the ground plane. As a result of which, bandwidth of 1.652 GHz (16.42% at the center frequency of 10.06 GHz) and a gain of 8.96 dB along with 5 different other operating bands are achieved. After integrating the microstrip antenna with the proposed defected ground structure, effective footprint of the antenna is reduced up to 66.95%. When integrated with proposed DGS array, the same antenna array structure shows miniaturization up to 78.97%. The proposed defected ground structure when compared to other techniques shows an exceptionally lower mutual coupling between two E-plane coupled microstrip antenna elements.

1. Introduction

The frequency response of various microwave components and circuits can be optimized by selecting the appropriated shape and size of the conductor lines. Since backside ground plane of these components, which is typically made up of metal sheet like copper, does not provide a degree of freedom in the design phase, defected ground structure (DGS) suggests an alternative solution to improve the characteristics of the microwave components that are based on microstrip lines and coplanar waveguides (CPW) [1]. Various slotted structures etched in the ground plane have been reported in [2,3]. Any modification or etching of the ground plane which alters its uniformity is generally called as “defect” [1]. It is positioned beneath a microstrip line or antenna and aligned for proper coupling to the microstrip line or antenna [4]. In DGS, the metallic ground plane is carefully etched for attaining the desired pass band, stop band and slow wave characteristics due to disturbance or perturbation of current distribution which in turn increases its effective capacitance and inductance [5,6]. This also influences the input impedance and current distribution of the antenna, thereby minimizing the size of the antenna with respect to the resonating frequency of the antenna [7]. This results in forbidden excitation and transmission of the EM waves through the dielectric layer [8]. Electromagnetic waves travelling in the DGS offer stop band and pass band characteristics over a range of frequencies, thereby leading to a slow wave structure [9].

There are two main categories of DGS: one group may include a single defect or unit cell and the other may include a series of small defects in periodic or non-periodic manner [10]. DGS of various shapes along with their applications are discussed in [11–18]. This work presents a novel defected ground structure. The performance of microstrip antennas and their array can be enhanced by introducing the defects in the ground plane. So, one dimensional (1-D) EBG structure or DGS is designed and analyzed. First of all, its design principle is discussed and then its application in array design is considered. The performance of the proposed DGS is evaluated and compared to that of conventional microstrip antenna with an ordinary ground plane. The design procedure, measurement techniques, and analysis of bandgap for a simple square type DGS (both positive and negative) has already been published in [19]. In this paper, a compact MSPA having 5 operating bands is proposed.

This paper is organized as follows. Section II describes the conventional MSPA and its associated parameters. First of all, optimization is performed on the dimensions of conventional MSPA to obtain the desired resonating frequency, i.e. 10 GHz. Thereafter, dimensional analysis of proposed DGS unit cell structure is done in Section III. Section IV describes the procedure to obtain the proposed defected ground structure unit cell. Section V describes the

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parametric study of each DGS dimension unit and their impact on the antenna characteristics, which finally gives rise to optimized proposed DGS structure. Section VI includes the impact of different array configurations of proposed DGS structure on the antenna characteristics. In Section VII, comparison of proposed DGS is performed with other mutual coupling reduction techniques in perspective of microstrip antenna array designing.

2. Single patch antenna design

Rogers RT/duroid 5880 ($\varepsilon_r = 2.2$, thickness, h = 1.6 mm, tan $\delta = 0.0009$) is chosen as dielectric material. The dimensions of ground plane are 50 mm × 50 mm. The following formulas are used for calculating the dimensions of the microstrip patch. For an efficient radiator operating at frequency f_r, placed on dielectric substrate of thickness h and permittivity ϵ_r, the actual width is given by:

$$W = \frac{c}{2f_r\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{1}$$

Substituting velocity of light, $c = 3.00 \times 10^8$ m/s, $\varepsilon_r = 2.2$ and $f_r = 10$ GHz, we get $W = 9.1224$ mm. The effective dielectric constant (due to fringing effect) is:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{2}$$

Putting $\varepsilon_r = 2.2$, $W = 9.122$ mm and $h = 1.6$ mm we get $\varepsilon_{eff} = 3.18$. Patch length extension at the two open ends due to fringing fields can be calculated as:

$$\Delta L = 0.412h\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} - 0.8\right)} \tag{3}$$

Replacing ε_{eff}, W, and h by their values, we get $\Delta L = 0.71537$. Patch length can be calculated as:

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2(\Delta L) \tag{4}$$

Putting $\varepsilon_{eff} = 3.1824$, we get $L = 6.9718$ mm. The feed used is microstrip feed which is 21.51407 mm long and 2.325 mm wide. The final dimensions of the conventional microstrip antenna and feed are given in Table 1. The impedance of the radiating patch can be approximately given as follows:

$$Z_a = \frac{90\varepsilon_r^2}{\varepsilon_r - 1}\left(\frac{L}{W}\right)^2 \tag{5}$$

The impedance of the patch comes out to be 299.32Ω. Since we are using microstrip feed, so for better impedance matching between the radiating patch and feed, the length and width of the feed are taken to be 2.325 and 21.514 mm.

Table 1
Design parameters of normal microstrip antenna after optimization.

Parameter	Value
λ_o	30 mm
Frequency of operation, f_o	10 GHz
Substrate	Rogers RT/duroid 5880
Substrate thickness, h	1.6 mm
ε_r	2.2
W	9.122 mm
L	6.9718 mm
W_f	2.325 mm
L_f	21.514 mm

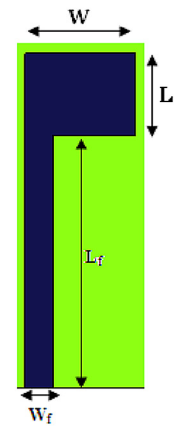

Fig. 1. Conventional microstrip patch antenna.

Fig. 1 shows an optimized conventional microstrip antenna above a non-defected ground plane which is designed to operate at around 10 GHz. Microstrip feed is used to excite the antenna. Since the return loss level and impedance bandwidth are affected with respect to the feeding location, the same is varied at a step of 0.25 mm starting from the extreme corner point moving towards the center of the microstrip patch or radiator. So, only that feeding point is selected where the values of return loss and impedance bandwidth is best. Here we are able to achieve the best results when the feed is used at extreme corner. Feed width (W_f) is also considered for better impedance matching as it affects the impedance nature of the radiating structure. Table 2shows the simulation results of conventional MSPA, showing very small value of %BW and gain.

Table 2
Simulation results for conventional MSPA.

S. No.	Conventional MSPA	Values	S. No.	Conventional MSPA	Values
1.	f_r (GHz)	9.9550	5.	BW	675 MHz
2.	S_{11} (dB)	−19.3287	6.	%BW	6.7875
3.	VSWR	1.2422	7.	FBR	156.945
4.	Gain (dB)	4.3841			

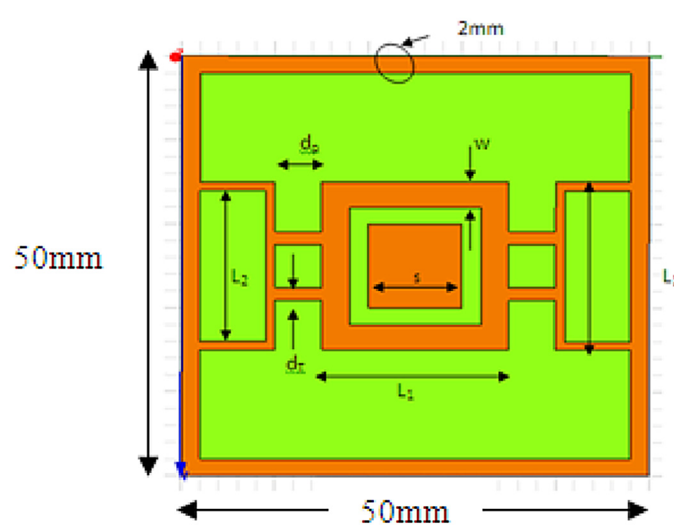

Fig. 2. Schematic representation of one unit cell of the proposed DGS structure (50 mm × 50 mm).