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Performance Optimization of a Microstrip Patch Antenna using Characteristic Mode and D/Q Analysis

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Abstract

A >30% 2:1 VSWR bandwidth using a coaxially fed microstrip patch antenna along the patch diagonal has been designed within the framework of two optimization techniques and is the focus of this work. For a center frequency (f_c) of 3.6 GHz, 53.5% bandwidth is achieved when the feed probe is placed at 2/3rd distance along the diagonal compared to a 15.7% bandwidth obtained, using the conventional offset fed design. Full wave simulation results are obtained by the FEKO solver and compared with measured data. Characteristic Mode Analysis (CMA) has been performed to identify the dominant eigencurrent modes, in the designed antennas. The approximate Quality Factors Q, applicable to electrically small antennas (ESAs), have been compared to the exact Q of the antenna calculated via antenna input impedance. Performance optimization of the antenna, in terms of both near- and far-field parameters, using the D/Q element optimization technique, has been investigated.

1 Introduction

Since the development of the first practical microstrip patch antennas in the 1970s, they have remained a popular choice among the antenna community, owing to their small size, light weight, conformability, and performance tractability [1]. However, one of the major drawbacks of a coaxially fed microstrip antenna continues to be its low matched VSWR bandwidth [1]. In this paper, a method has been proposed to enhance the bandwidth of a simple probe fed patch antenna via strategically placing the probe along the patch diagonal.

The performance of the designed antenna, in terms of VSWR and gain, have been compared to the conventional antenna designs available in the literature [1]. Characteristic mode analysis of the antennas, via TCM solver available in FEKO, have been performed to identify the contributing modes in each case [2].

The exact Quality Factor Q of the antenna, calculated via antenna input impedance [3], and the approximate Q's, computed using the expressions reported by Harrington [4], McLean [5], Thal [6] *et al.* are compared to the measured Q. Performance optimization of the designed antenna using D/Q optimization technique [7] is being investigated.

2 Antenna Design

2.1 Antenna I

A rectangular microstrip patch is designed on a 6.35 mm thick TMM-10i substrate ($\varepsilon_r = 9.8, \tan\delta = 0.0020$). The patch dimensions are calculated for a design frequency of 3.6 GHz using the relations given in [8], with the probe placed along the X-axis at an offset distance from the center. The antenna geometry has been shown in Figure 1(b).

2.2 Antenna II

The probe is now moved along the patch diagonal without altering the antenna dimensions. Maximum bandwidth is recorded when the probe is placed at 2/3rd distance between the center and the vertex of the patch as shown in Figure 1(c).

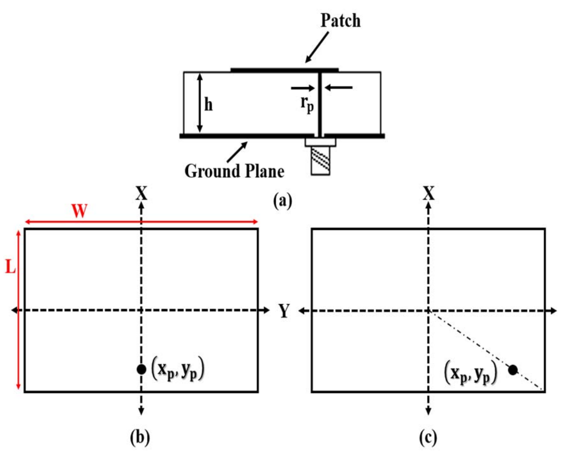

Figure 1. (a) Side view of the rectangular microstrip antenna. Top view of the patch for (b) Antenna I with (xp, yp) = (3.5 mm, 0 mm) and (c) Antenna II with (xp, yp) = (3.20 mm, 4.80 mm)

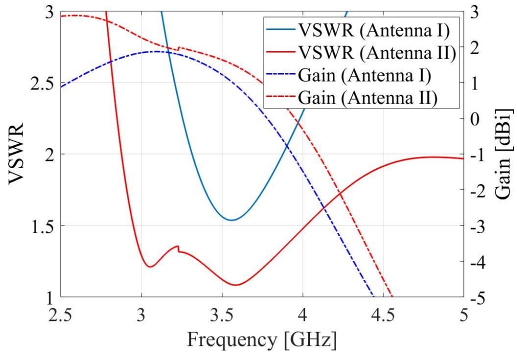

Figure 2. Comparison between the VSWR and Gain of Antenna I and II on infinite ground plane having L=9.61 mm, W=14.42 mm, and r_p=0.6 mm

Table 1. Simulated antenna parameters

Antenna	f_L (GHz)	f_c (GHz)	f_U (GHz)	%BW	Max Gain (dB)
I	3.315	3.5975	3.88	15.70	1.86
II	2.878	3.792	4.706	48.20	2.87

3 Calculation of Quality Factors

The exact Q of the antenna at any frequency ω can be calculated via its input impedance $Z_0(\omega) = R_0(\omega) + jX_0(\omega)$ as [3]:

$$Q(\omega_0) \approx \frac{2\sqrt{\beta}}{FBW_v(\omega_0)} \quad (1)$$

where, fractional bandwidth,

$$FBW_v(\omega_0) = \frac{\omega_- - \omega_+}{\omega_0} \quad (2)$$

β is calculated using the relation:

$$4\beta R_0(\omega_0) = \frac{X_0^2(\omega_\pm) + [R_0(\omega_\pm) - R_0(\omega_0)]^2}{R_0(\omega_\pm)} \quad (3)$$

Several approximate Q expressions, applicable for ESAs, are available in the literature [4-6]. For an antenna to qualify as electrically small, its electrical length, ka, should be < 1; k and a being the wavenumber and the radius of Chu's sphere respectively [9]. For the designed antenna, the ka value is calculated by considering the diameter of the Chu's sphere to be equal to the patch diagonal, i.e.

$$\sqrt{L^2 + W^2} = 2a \quad (4)$$

The designed antenna (Antenna II) can, hence, be classified as an ESA since it's $ka = 0.68$. The exact Q of the antenna, calculated using Eq. (1), has been compared to the approximate Q expressions (enlisted in Table 2) and the measured Q as shown in section 5.

Table 2. Approximate Q Expressions

Reference	Quality Factor
[4]	$Q = \frac{1}{2}\left[\frac{1}{(ka)} + \frac{1}{(ka)^3}\right]$
[5]	$Q = \frac{1}{2}\left[\frac{2}{(ka)} + \frac{1}{(ka)^3}\right]$
[6]	$Q = \frac{1}{(ka)^3}$

4 Characteristic Mode Analysis

Characteristic Mode Analysis (CMA) has been carried out for Antennas I and II on infinite substrates using FEKO. Modal behaviors of the antennas are illustrated via modal significance (MS_n) curves, which can be defined as [2]:

$$MS_n = \frac{1}{|1 + j\lambda_n|} \quad (5)$$

where, λ_n refers to the eigenvalue for the n-th eigencurrent. The n-th eigencurrent is said to be dominant when $\lambda_n \approx 0$ or $MS_n \to 1$.

Figures 3 and 4 compare the MS_n and VSWR of both Antennas I and II, respectively. For Antenna I, mode J3 is observed to have the maximum contribution, while for Antenna II, modes J1 and J3 are found to be significantly dominant.

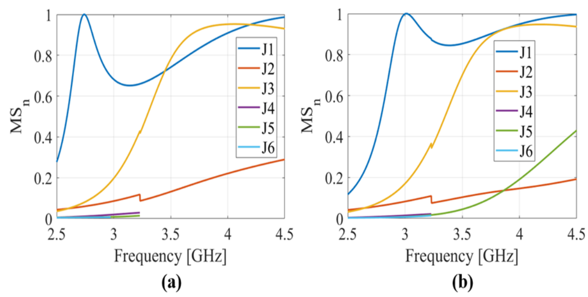

Figure 3. Modal Significance for (a) Antenna I and (b) Antenna II, both having L=9.61 mm, W=14.42 mm, and r_p=0.6 mm.

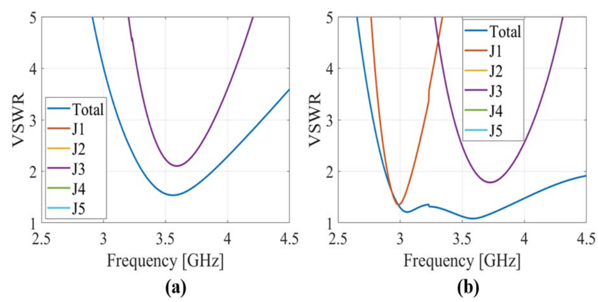

Figure 4. VSWR of (a) Antenna I and (b) Antenna II, having L=9.61 mm, W=14.42 mm, and r_p=0.6 mm.

5 Experimental Results

Antenna II has been modeled on square and circular finite ground planes and the simulated results show remarkable enhancement in gain. A maximum simulated gain of 5.65 dBi is recorded for the antenna in case of a circular grounded substrate. Figure 5(a) shows the fabricated prototype on a circular ground plane of radius 2.35 cm. A comparison between the measured and the simulated VSWR is shown in Figure 5(c). Table 3 summarizes the comparison between simulated and measured results.

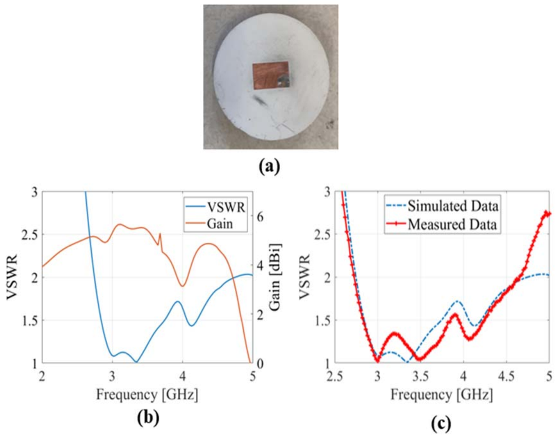

Figure 5. (a) Fabricated prototype of Antenna II; (b) Simulated VSWR and Gain, (c) Measured and simulated VSWR on circular ground plane. The results refer to Antenna II.

Table 3. Antenna Parameters

	f_L (GHz)	f_c (GHz)	f_U (GHz)	BW (%)	ka
Simulated	2.745	3.7475	4.75	53.5	0.68
Measured	2.72	3.69	4.66	52.6	0.67

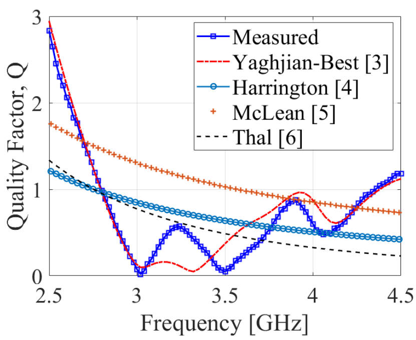

Figure 6. Simulated and Measured Q of the designed microstrip antenna-Antenna II.

The various Q's of the proposed antenna (Antenna II) have been compared with the measured Q in Figure 6. It is observed that the approximate Q expressions given by Harrington [4], McLean [5], Thal [6] do not agree well with the measured Q.

One of the useful multi-parameter element optimization techniques is the D/Q ratio of the antennas [7]. Using this method it is possible to optimize the far field parameter (i.e., D or Directivity) and the near field parameter (Q) simultaneously. The D/Q ratio for Antenna II is plotted as a function of frequency in Figure 7. Directivity values are obtained from FEKO and Q is calculated using Eq. (1).

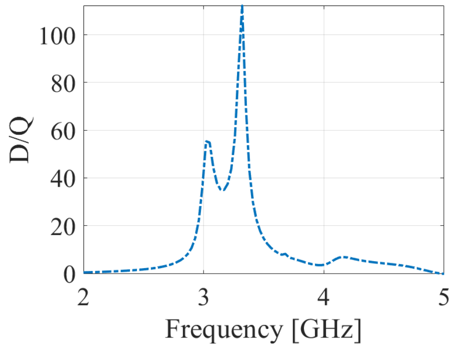

Figure 7. Simulated D/Q ratio of Antenna II as a function of Frequency. Directivity and antenna input impedance (for calculating the Exact Q [3]) are extracted from FEKO.

6 Summary

In this paper, a method to achieve > 30% 2:1 VSWR bandwidth using a coaxially fed rectangular patch has been presented. 53.5% bandwidth with 5.65 dBi of peak gain has been obtained from a simple patch, designed at 3.6 GHz, when the probe is placed at 2/3rd distance along the patch diagonal. Measured VSWR is shown to have good agreement with the simulated results obtained via FEKO. Theory of characteristic mode has been investigated to identify the dominant eigencurrent modes for the design. Quality factors of the proposed antenna, computed using the approximate [4-6] and the exact Q expressions [3], are compared to the measured data. It has been shown that the approximate Q's do not agree well with the measured Q unlike the exact Q, which appears to be more relevant. Performance optimization of the antenna using the multi-parameter D/Q ratio has been investigated and will be presented in detail at the conference.

7 Acknowledgements

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