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Analysis of Circular Stacked Microstrip Antenna for Bandwidth Enhancement

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Abstract

A circular microstrip stacked antenna is analyzed and investigated. It is observed that stacked antenna shows marked improvement in the bandwidth, gain and directivity over the single element. It is further observed that both resonance frequency and gain are highly dependent on the thickness and dielectric of the upper substrate and its permittivity. Typically the stacked antenna shows enhanced bandwidth of 16% as compared to 6% of single layer circular microstrip antenna.

Introduction

Microstrip antennas are well suited due to their low weight, low profile with conformability and low manufacturing cost. However the major drawbacks of microstrip antenna are low gain and narrow bandwidth [1]. In the present endeavor, an attempt has been made to enhance the bandwidth of microstrip antenna (consisting of a driven patch in the bottom and a parasitic element on the top) [2]. The proposed model for stacked antenna is based on the circuit theory concept, which is used to calculate the input impedance, bandwidth and ration pattern.

Theoretical Considerations

Two-layer stacked patch

Due to the presence of the parasitic element in the stacked configuration as shown in fig.1(a), there are two resonance associated with the resonator formed by the lower patch and the ground plane and the second resonance is associated with the resonator formed by the parasitic patch and lower patch.

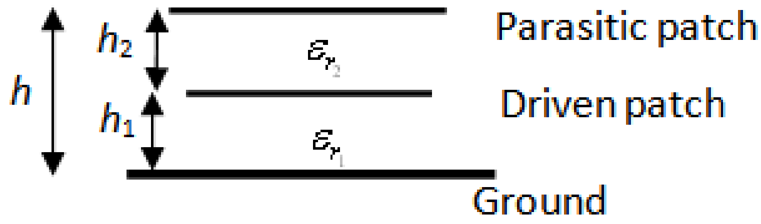

Figure 1(a): Side-view of two layers stacked microstrip antenna.

The first resonator is considered as a microstrip patch with dielectric cover (superstrate). Due to the presence of superstrate the effective dielectric constant is changed and the resonance frequency will decrease with thickness and the dielectric constant of the superstrate [5]. The effective dielectric constant, the present microstrip configuration can be represented as a single patch with a semi-infinite superstrate with relative dielectric constant equal to ε_{r_1},which is given as

$$\varepsilon_{r_1} = \frac{2\varepsilon_{eff}-1+\rho}{1+\rho}, \rho = (1 + 10h_1/a_e)^{-1/2}$$

The modal expansion cavity model of the two resonators is shown in fig.1(b) & 1(c) and the values of the circuit parameters are given as [1].

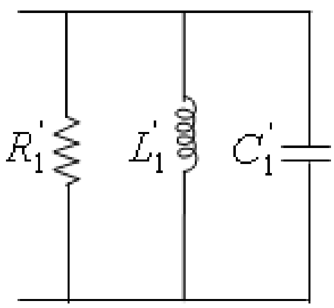

Figure 1 (b): Equivalent circuit of first resonator.

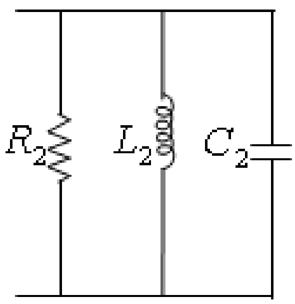

Figure 1(c): Equivalent circuit of the second resonator.

The coupling factor C_p between the two resonators may be given as[6]

$$C_P = 1/\sqrt{Q_{T_1} Q_{T_2}}$$

Where Q_{T_1}& $Q_{T_2}$are the total quality factor of the resonator first and second respectively. Considering both inductive and capacitive coupling, the resulting equivalent circuit of the stacked antenna can be represented as shown in fig.2 and the values of mutual inductance L_m and mutual capacitance C_m are defined as [5]

$$L_m = \frac{C_p^2(L_1'+L_2)\sqrt{\left(C_p^4(L_1'+L_2)^2+4C_p^2(1-C_p^2)L_1'L^2\right)}}{2(1-C_p^2)}$$

$$C_m = \frac{-(C_1'+C_2)+\sqrt{\left((C_1'+C_2)^2-4C_1'C_2(1-1/C_p^2)\right)}}{2}$$

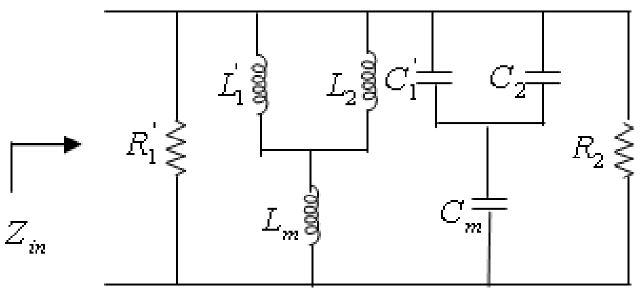

Figure 2: Equivalent circuit of stacked circular microstrip antenna.

Now the input impedance of the stacked microstrip antenna according to fig.3 is given by

$$Z_{in} = \frac{\omega^2 RL^2 + j\omega R^2 L(1-\omega^2 LC)}{\omega^2(\omega^2 R^2 L^2 C^2 - 2R^2 LC + L^2) + R^2}$$

Where $\omega = 2\pi f$

$$R = \frac{R_1 R_2}{(R_1+R_2)}$$

$$L = \frac{L_1' L_2}{L_1'+L_2} + L_m$$

$$C = \frac{(C_1'+C_2)C_m}{C_1'+C_2+C_m}$$

The E-plane (x-y plane) radiation field of the circular microstrip patch antenna can be given as [1] for $-90^\circ \leq \emptyset \leq 90^\circ$

$$E_1(\emptyset) = j\frac{k_0 a_{e_1} V_o e^{-jk_o r_1}}{2r_1}[J_{02}']$$

Where $J'_{02} = J_0\left(k_0 a_{e_1} sin\emptyset\right) - J_2\left(k_0 a_{e_1} sin\emptyset\right)$

The induced slot voltage of the parasitic patch is C_p times the slot voltage of the driven patch[6] and hence the radiated field of the stacked antenna in E-plane, can be given as

$$E(\emptyset) = j\,\frac{k_0 a_{e_1} V_o e^{-jk_o r_1}}{2r_1}\,[J'_{02}] + j\,\frac{k_0 a_{e_2} V_o e^{-jk_o r_2}}{2r_2}\,[J'_{02}]$$

Design Specifications and Calculations

The center design frequency of both single layer basic circular microstrip antenna and two layer stacked microstrip antenna is 10 GHz. The designed parameters of single and stacked patch are shown in Table 1 and 2 respectively.

Single-layer microstrip patch	Two-layer stacked microstrip patch	
	Lower patch	Upper patch
a_1 = 5.9 mm	a'_1 =5.9 mm	a_2 =5.6 mm
h_1=1.2 mm	h_1=1.2 mm	h_2=1.2 mm
ε_{r_1}=2.2	ε_{r_1} =2.2	ε_{r_2}=2.4

The calculated values of input impedance and bandwidth of above designed patches are:

Single patch	Stacked patch
Z_{in}=286	Z_{in}=141
% BW=4	% BW=15.8

Discussion of Results

The designed parameters of circular microstrip patch antenna at 10 GHz is shown in Table 1. By using the same patch in stacked configuration, the effect of upper substrate, thickness (h_2) and permittivity (ε_{r2}) were studied and the results are shown in fig. (3-4). It is observed that (Fig.3(a)) that the stacking of the patch with parasitic element of same dimension reduces the input resistance from 286 ohms to 141 ohms and the resonance frequency reduces from 10 GHz to 9.6 GHz. It is further observed that increasing the thickness of the upper substrate (h_2) the resonance frequency of the stacked antenna decreases with small increase in resonance resistance while the resistance curves widens. The VSWR and Return loss graph for increasing the upper substrate (h_2) and the resonant frequency of stacked antenna are shown in Fig.3 (b) and Fig.3 (c) respectively. From Fig.3 (d) it is found that the gain and directivity of the stacked antenna are slightly greater than that of the single patch antenna and increases with thickness of the upper substrate due to the fact that as coupling factor C_P increases, the total quality factor of second resonator decreases. Similar observations were also made by Lee and Lee[8].From Fig.4 (a), it is observed that as the permittivity of the upper substrate (ε_{r2}) increases, the resonance frequency decreases with small increase in the resonance resistance, while the increase in the permittivity further increases the resonance frequency with small increase in the resonance resistance. The VSWR and Return loss graph for increasing the permittivity (ε_{r2}) of upper substrate and the resonant frequency of stacked antenna are shown in Fig.4 (b) and Fig.4 (c) respectively. From Fig.4 (d) shows the gain from single patch antenna and the beam width widens with the increase in the permittivity of the upper patch. From the above observations it is clear that for wide bandwidth, the h_2 should be high and ε_{r2}must also be high as observed by Arnan Mittchell et al[3]. An increase in the thickness h_2 reduces the same center frequency the patch dimensions must be reduced which may reduce the radiated power i.e antenna efficiency. Hence a compromise has to be made between bandwidth and radiated power. Thus in order to have design frequency of 10 GHz for stacked antenna an adjustment in the patch dimension was done by taking the height (h_2) of the upper substrate as minimum and the permittivity (ε_{r2}) of the upper substrate as maximum, the resulting parameter of this investigation are given in Table 1 and Table 2. The VSWR, Return Loss and radiation pattern of these designed antennas are shown in Fig.5 (a), Fig.5 (b) and Fig.5 (c) respectively. From Fig.5 (a) and Fig.5 (b), it is observed that for a coaxial fed; the bandwidth of the stacked antenna improves to 16% as compared to 6% of single layer microstrip antenna patch. The gain of the stacked antenna is 6.021 dB (Fig.5(c)) over single layer microstrip antenna. It is further observed (Fig.5(c)) that the beam width of the stacked antenna improves to 1.4^0 as compared to 1.7^0 of a single layer microstrip antenna.

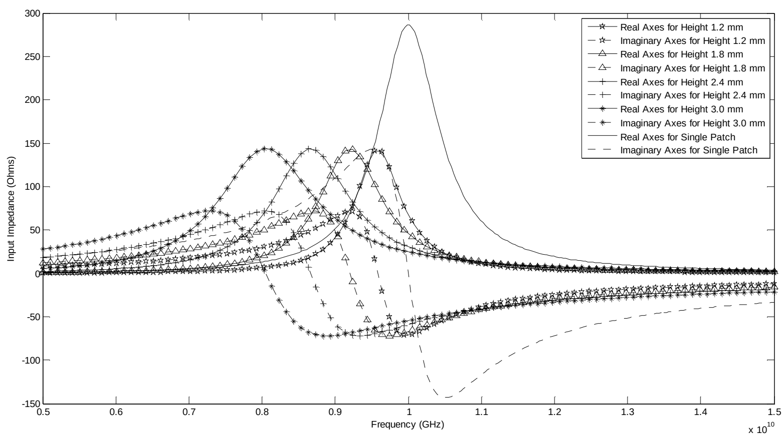

Figure 3 (a): Variation of input impedance with frequency for different value of h_2

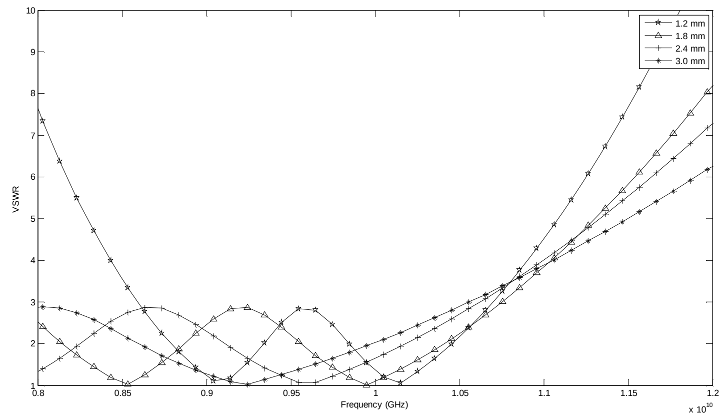

Figure 3(b): Variation of VSWR with frequency for different value of h_2

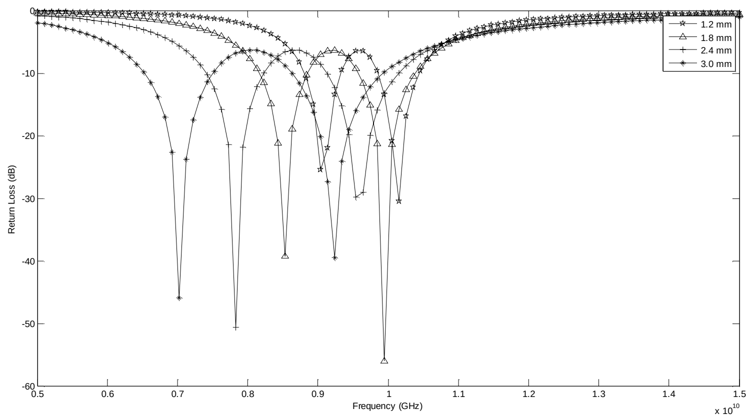

Figure 3(c): Variation of Return Loss with frequency for different value of h_2

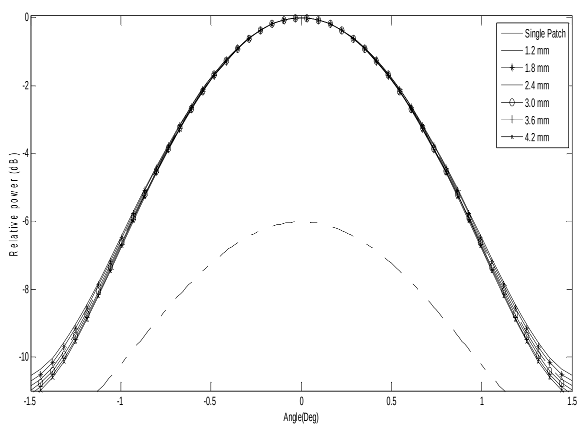

Figure 3(d): E-plane radiation pattern for different value of h_2

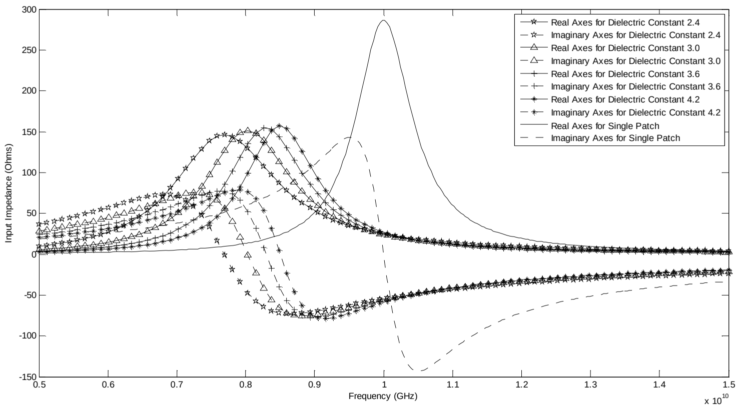

Figure 4(a): Variation of input impedance with frequency for different value of ε_{r2}

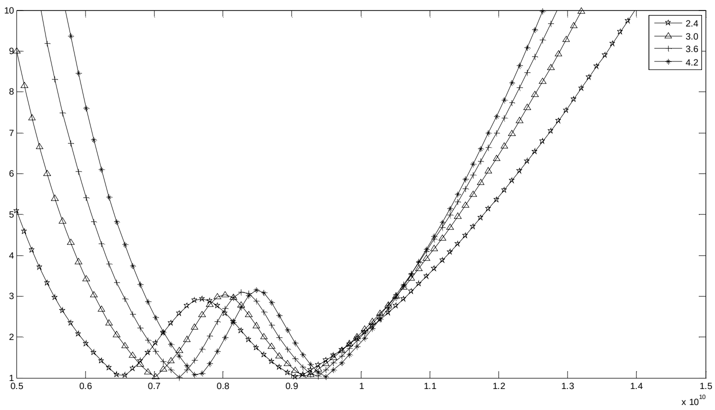

Figure 4(b): Variation of VSWR with frequency for different value of ε_{r2}

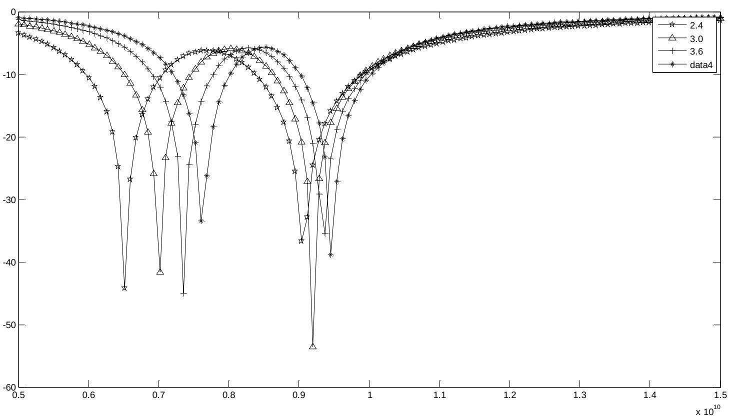

Figure 4(c): Variation of Return Loss with frequency for different value of ε_{r2}

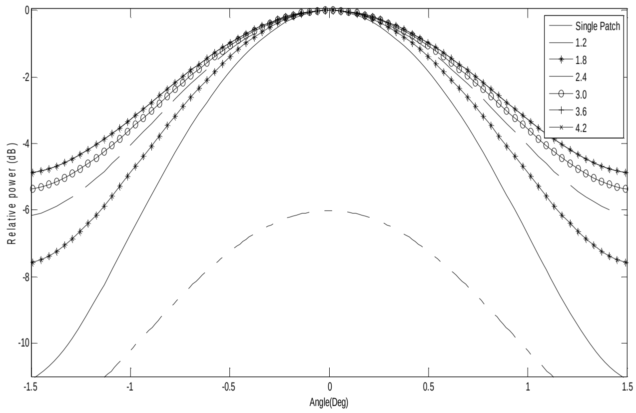

Figure 4(d): E-plane Radiation pattern for different value of ε_{r2}

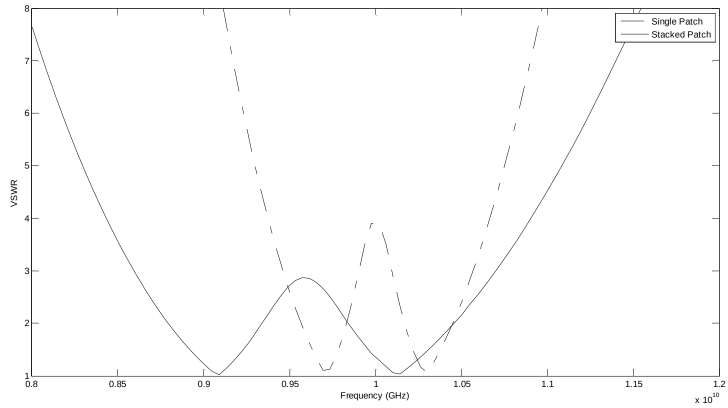

Figure 5(a): Variation of VSWR with frequency for single and stacked antenna

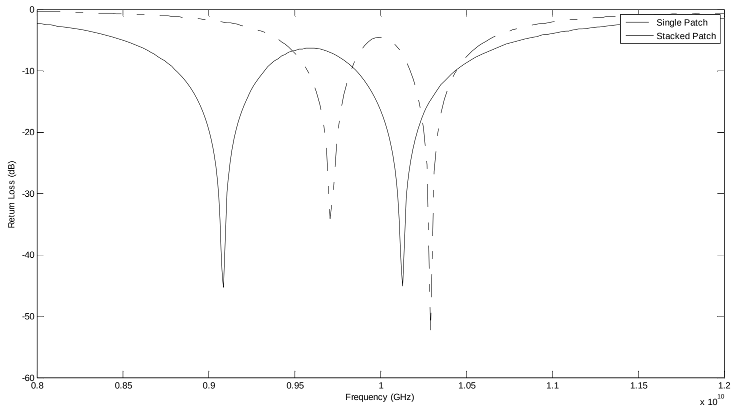

Figure 5(b): Variation of Return Loss with frequency for single and stacked antenna

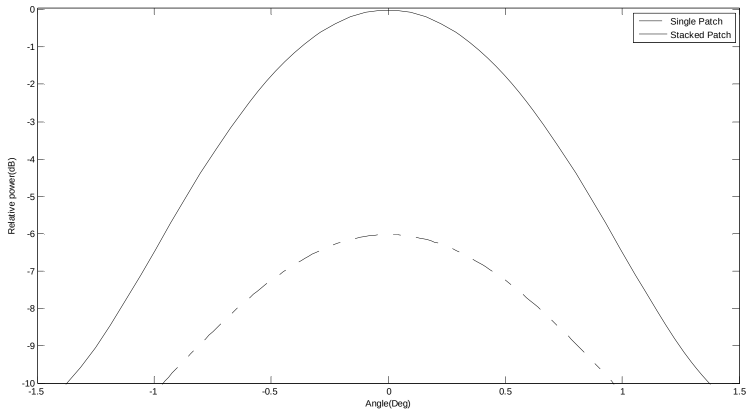

Figure 5(c): E-plane radiation pattern for single and stacked antenna

Conclusion

The developed model for stacked antenna gives all most comparable results to the simulated results by Kai Fong and Wei Chen [7]. This verifies the validity of the developed model. It is also concluded that the thickness and permittivity of upper substrate play an important role in controlling the resonance behavior of stacked antenna.

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