Analysis of Stacked Microstrip Antenna using FDTD Method

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1 Introduction

Although a microstrip antenna has advantages such as low-profile and light weight, a single patch antenna has a low gain (5-8 dBi) and a narrow bandwidth. By stacking a parasitic element on a microstrip patch antenna, the antenna with high gain or wide bandwidth can be realized[1]. These characteristics of stacked microstrip antenna depend on the distance between a fed element and a parasitic element. When the distance is about 0.1 λ (wavelength), the stacked microstrip antenna has a wide bandwidth[1, 2]. The stacked microstrip antenna has been analyzed numerically by using the spectral domain method[2]. It has been experimentally shown that the stacked microstrip antenna has a high gain when the distance between the fed element and parasitic element is 0.3 to 0.5λ[1, 3].

In this paper, the finite-difference time-domain (FDTD) method is applied to the stacked microstrip antenna. Berenger's perfectly matched layer (PML) with 10 cells is applied as the absorbing boundary condition. The input impedance, the directivity, and the near field distribution are calculated very accurately and the relation between the wideband and the gain enhancement and the calculated near field distributions of the stackd microstorip antennas are firstly described in detail.

2 Model for Analysis

Fig.1 shows the geometry of the stacked microstrip antennas. This microstrip antenna is composed of the probe-fed square patch antenna and the parasitic square patch. The fed element is designed to have a resonant frequency of 7.5GHz. These elements are etched on a dielectric substrate(length=l_g, relative dielectric constant $\epsilon_r = 2.15$, thickness $d = 0.8$mm). The parasitic element is stacked at the height h_p above the fed element and supported by the foam spacer with low dielectric loss.

The space steps used in the FDTD formulation are $\Delta x = \Delta y = 0.612$mm and $\Delta z = 0.8$mm and the size of free space is $60\Delta x \times 60\Delta y \times 60\Delta z$. The time step is taken to be $\Delta t = 1.2696$ps to satisfy the Courant stability condition. The size of the ground plane and the fed patch are $40\Delta x \times 40\Delta y(24.48 \times 24.48mm = 0.612 \times 0.612\lambda)$ and $20\Delta x \times 20\Delta y(12.24 \times 12.24mm = 0.306 \times 306\lambda)$, respectively. The parasitc element size l_p equals the fed element size l_f. The far field is calculated from the equivalent electric and magnetic currents on the surface defined 5 cell inside of the absorbing boundary[4].

The antenna is excited by a Gaussian pulse electric field in the feed point gap$(i_f, j_f, k_f + 1/2)$.

3 Results and Discussion

Fig.2 shows the frequency characteristics of input impedance of the stacked microstrip antenna. In the figure, the input impedance of the single patch antenna is also shown to be compared with those of the stacked microstrip antennas. When the hight h_p is 0.5λ, the real part of input impedance is increased at the resonant frequency and bandwidth becomes narrow. When the hight h_p is 0.1λ, the antenna has two resonant frequency and the impedance remains stable.

Fig.3 and Fig.4 show the current Jx of center of fed element and parasitic element respectively. These current amplitude are normalized by the maximum amplitude of single patch antenna. At each resonant frequency, the amplitude of the current Jx increases to maximum and the phase varies. When hight h_p is 0.1λ, the changes of amplitude and phase of current Jx are smaller than other the antennas, so that the stacked antenna has wide bandwidth. When hight h_p is 0.5λ, the stack antenna has a resonant frequency. The amplitude and phase of the stacked antenna with h_p=0.5λ change largely at the resonant frequency, so that impedance bandwidth becomes narrow.

Fig.5 shows the calculated directivities of the stacked microstrip antenna as a function of the hight h_p. Fig.6 shows the near field Hy on the center of upper surface of the parasitic element as a function of the hight h_p. These Hy are expressed in values relative to the Hy on the center of the fed element. The directivity increases by stacking the parasitic element. When the larger directivity is obtained, the relative amplitude are increased. The gain increases to the maximum at $h_p = 0.5\lambda$. When the maximum gain is obtained, the Hy amplitude on the parasitic element increases and the phase difference of Hy between the parasitic element and the fed element becomes 180°. The maximum gain of 9.42dBi is higher than that of the single patch antenna by 1.79dB.

Fig.7 and Fig.8 show the Ex and Hy distribution of the stacked microstrip antenna in the z-direction including the center of antenna respectively. The amplitude of the each distribution of the antennas are normalized by its input power. The amplitude of Ex and Hy is normalized by the maximum amplitude of single patch antenna. And the phase of Ex and Hy at the fed element is set to be zero. In the case of maximum gain ($h_p = 0.5\lambda$), there is the standing wave between the fed element and the parasitic element. The electromagnetic field from the fed element reflects at the parasitic element and the standing wave occurs between the fed element and the parasitic element. The space between the fed element and parasitic element is simuler to a resonator. Decreasing the height h_p to 0.1λ, the amplitude of Ex decreases and the resonant effect fades away.

4 Conclusion

The probe-fed square patch microstrip antenna with a stacked parasitic patch has been calculated by using FDTD method. The input impedance, the directivity and the near field distributions have been calculated and the relation between the wideband and the gain enhancement and the antenna structure has been investigated. The bandwidth and directivity of stacked microstrip antennas are dependent on the hight parasitic element. When hight h_p is about 0.1 wavelength, the impedance bandwidth becomes wider. The stacked antenna has two resonant frequency and the changes of current amplitude and phase of elements are smaller than other antennas. Increasing the hight h_p to about a half wavelength, the impedance bandwidth becomes narrow but the high gain is obtained. The current of elements change largely at the resonant frequency, so that the impedance bandwidth becomes narrow. However, the space between the fed element and parasitic element like a resonator, so that high gain is obtained.

The highly accurate near field analysis by the FDTD method makes it clear that the relation between the wideband and the gain enhancement and the the parasitic elements.

References

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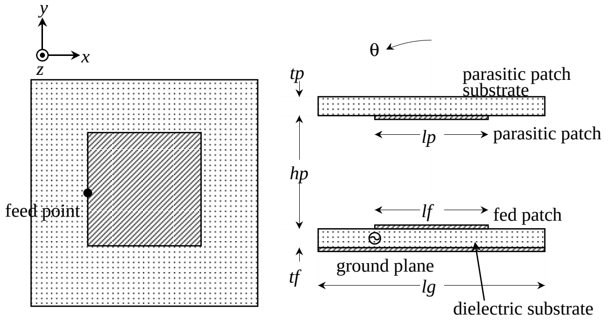


(a) top view

(b) side view

Figure 1: Structure of stacked microstrip antenna.

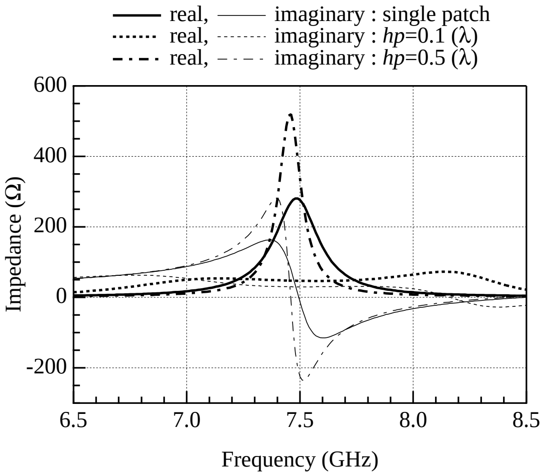
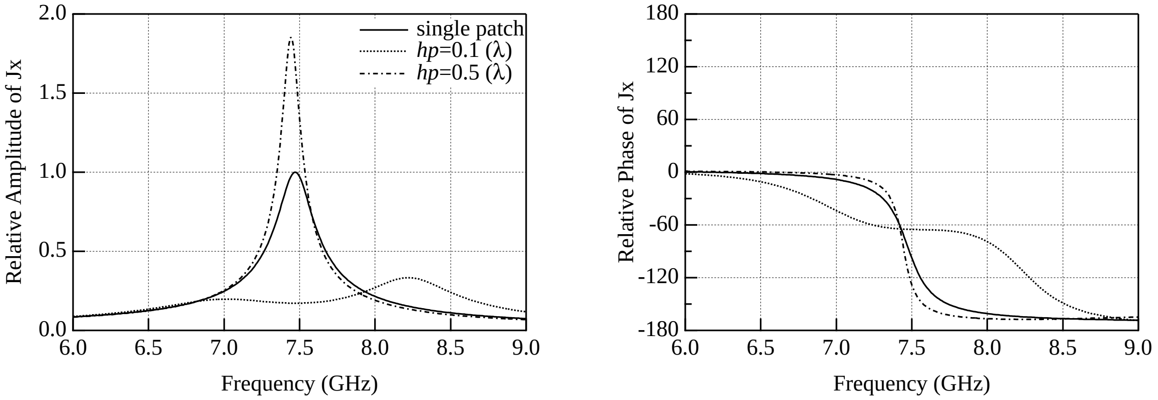


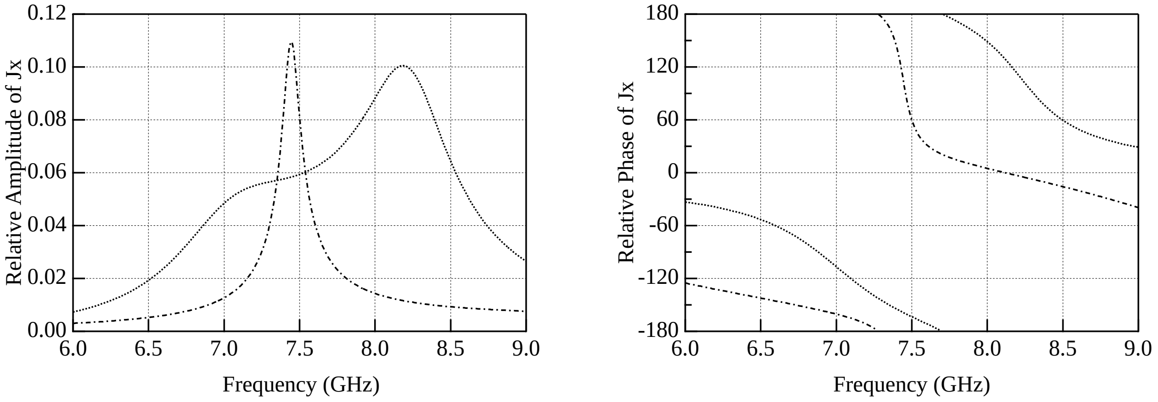
Figure 2: Input impedance.



(a) Amplitude

(a) Phase

Figure 3: Current Jx of fed element. (Frequency 7.5GHz)



(b) Amplitude

(b) Phase

Figure 4: Current Jx of parasitic element. (Frequency 7.5GHz)

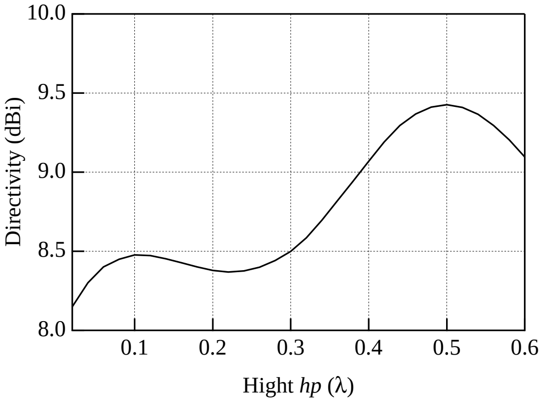


Figure 5: Directivity. (Frequency 7.5GHz)

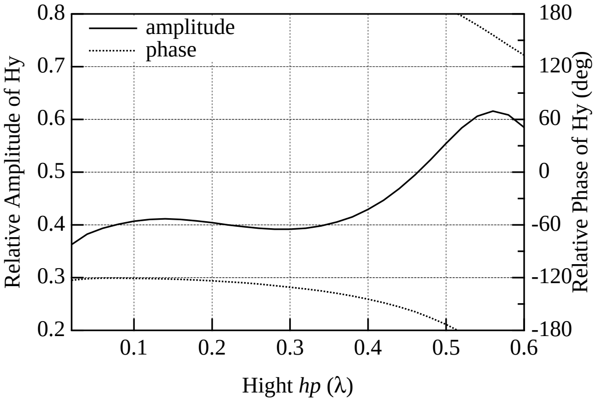
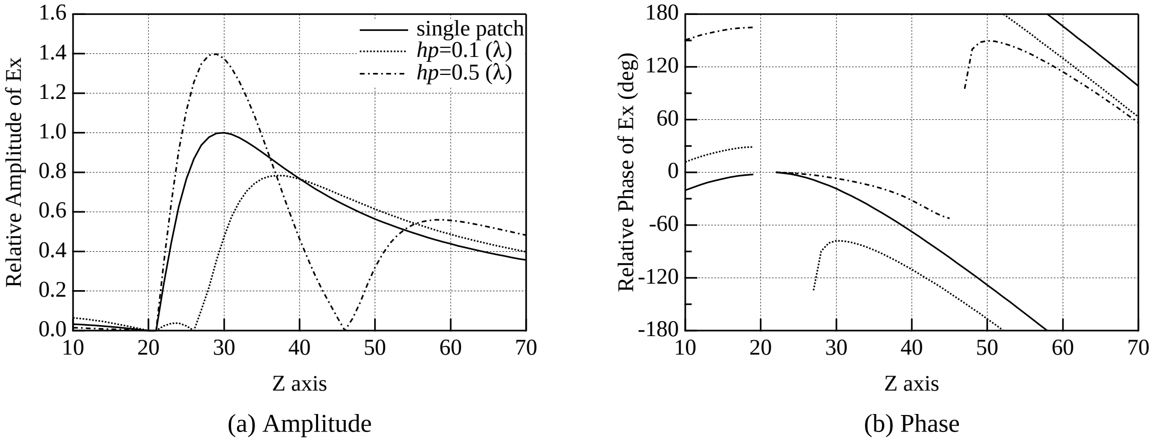


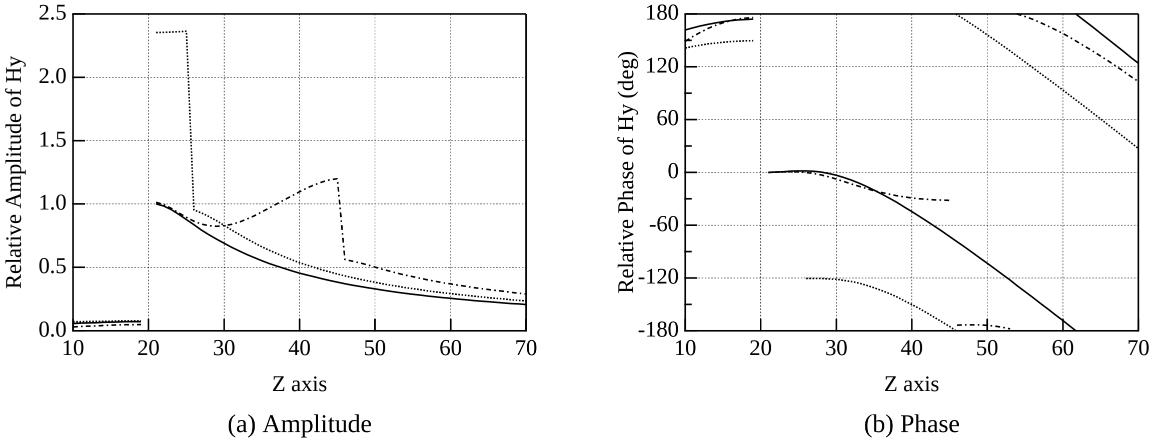
Figure 6: Relative value Hy on elements. (Frequency 7.5GHz)



(a) Amplitude

(b) Phase

Figure 7: Distributions of Ex in the z-direction. (Frequency 7.5GHz)



(a) Amplitude

(b) Phase

Figure 8: Distributions of Hy in the z-direction. (Frequency 7.5GHz)