Low-Profile Multi-Mode Wideband Patch Antennas

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***Abstract-* In this paper, a mini-review of the research and development of our proposed low-profile multi-mode wideband patch antennas is extensively provided. Firstly, a large number of traditional bandwidth enhancement approaches of the microstrip patch antennas (MPA) have been presented and comparatively described. The results illustrate that our proposed design concept of reallocation of multi-mode resonances of the MPA in proximity to each other is an effective way to achieve a wide-bandwidth for the antenna, while keeping a low-profile property. After that, the working principle about how to achieve the wideband performance for the MPA under radiation of several radiative modes is investigated. Finally, the further works about multi-mode wideband MPA are performed.**

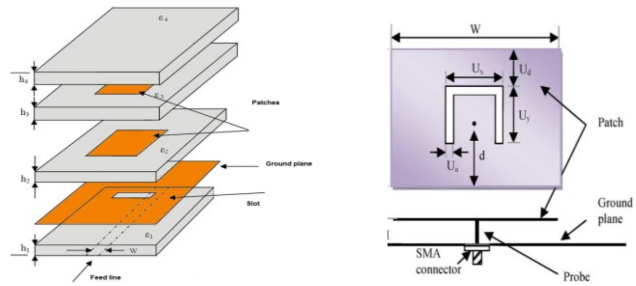
I. INTRODUCTION

With the development of modern communication systems, microstrip patch antennas (MPAs) have been extensively investigated and developed over these years. Their indices and requirements are becoming more and more rigorous to the direction of low profile and wideband applications. Unfortunately, the traditional MPA, especially with a low profile, inherently suffers from a narrow impedance bandwidth due to the single-resonance radiation [1] and [2]. In order to overcome this problem, a few effective approaches have been proposed to enhance its impedance bandwidth.

A) Adding the parasitic element: a parasitic element could be mounted vertically above the radiating patch to create an additional resonance for bandwidth-improvement. In [3] and [4], the main radiating patch stacked with the parasitic element was employed to achieve a wide-bandwidth of above 25%. However, the additional patch increases the profile of the antenna up to about 0.14 λ_0 (λ_0 is the free space wavelength) substantially.

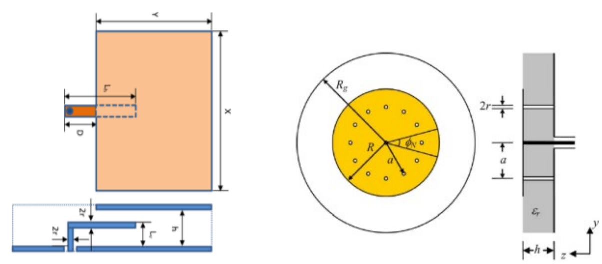
B) Improving the feeding structure: Next, the feeding scheme was alternatively designed to widen the impedance bandwidth. By introducing a tapered feeding strip, the operating bandwidth of the MPAs in [5] and [6] was dramatically extended to above 28.2%. Nevertheless, the feeding scheme is difficult to be implemented in an electrically thin substrate of below 0.06 λ_0.

C) Using the cascaded triangular cavities: the cascaded triangular cavities [7] instead of a single one were introduced to raise its impedance bandwidth up to about 33.11%. Whereas, the length and height of the antenna is unfortunately enlarged to about 2.83 λ_0 and 0.11 λ_0, respectively.



(a) (b)

Fig. 1 Two existing approaches for bandwidth enhancement of the MPAs. (a) Adding the parasitic element [3]. (b) Cutting the U-shaped slot [10].



(a) (b)

Fig. 2 Two additional existing approaches for bandwidth enhancement of the MPAs. (a) Using improved L-shaped feeding scheme [8]. (b) Combining several resonant modes of the MPA [12].

D) Introducing the capacitive coupled probe: In [8] and [9], a capacitive coupled probe was introduced to excite an additional non-radiative mode closely to its dominant mode of the core patch radiator, leading to a wide bandwidth of above 36%. But, both of these antennas also suffer from a high profile of above 0.06 λ_0.

E) Cutting a narrow slot on the radiating patch: By introducing a U-shaped slot with a long probe action as a series-resonant element, the operating bandwidth of the MPA in [10] reached to about 47%. Whereas, the height of these antennas is kept as large as above 0.08 λ_g (λ_g is the guided wavelength), thus destroying the intrinsic low profile or planar property.

F) Reallocating several radiative resonant modes: In order to achieve a low profile wideband performance, the TM_{10} and TM_{01} modes of a rectangular MPA [11] were adopted and excited simultaneously. In this way, the antenna gained a widened bandwidth of about 3.8% with the thickness of about 0.01 λ_0. The antennas in [12]-[13] obtained an impedance bandwidth above 12.48% by using two radiative

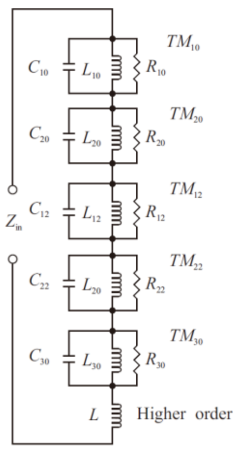


Fig. 3. General network model for the MPA under radiation of different resonant modes.

resonant modes. The works in [14-16] acquired an enhanced bandwidth of about 13% under radiation of dual odd-order modes. Compared to other previous works, the design concept of reallocation of multi-mode resonances of the MPA in proximity to each other for bandwidth enhancement has several advantages, such as low profile property and stable normal radiation patterns.

II. Working Principle

In this section, the operating principle of the proposed patch antenna with enhancement of impedance bandwidth under dual-/triple-mode resonances is extensively studied. As is well known, the traditional MPA with the dielectric constant and thickness of about 1.08 and 0.06 λ_0 usually achieves a narrow bandwidth of about 7.5 % [1], due to its intrinsic property of a single-resonance radiation. The general network of the MPA under radiation of different resonant modes is provided in Fig. 3. It can be seen that both the dominant TM_{10} mode and higher modes could be excited for the MPA in a single patch resonator.

Based on the previous work, the impedance bandwidth (B) of the antenna with respect to a maximum allowable voltage standing-wave ratio (VSWR) can be defined as

$$B(\%)=\frac{100(VSWR-1)}{Q\sqrt{VSWR}} \tag{1}$$

where Q stands for the unloaded quality factor of the MPA, and it can be written as

$$\frac{1}{Q}=\frac{1}{Q_r}+\frac{1}{Q_d}+\frac{1}{Q_c} \tag{2}$$

From (1), one can figure out that the bandwidth B of the antenna can be effectively increased by reducing its quality factor Q, which is determined by the radiation Q (Q_r), dielectric Q (Q_d), and conductor Q (Q_c). In this work, our main target is to increase the bandwidth of the MPA with slight

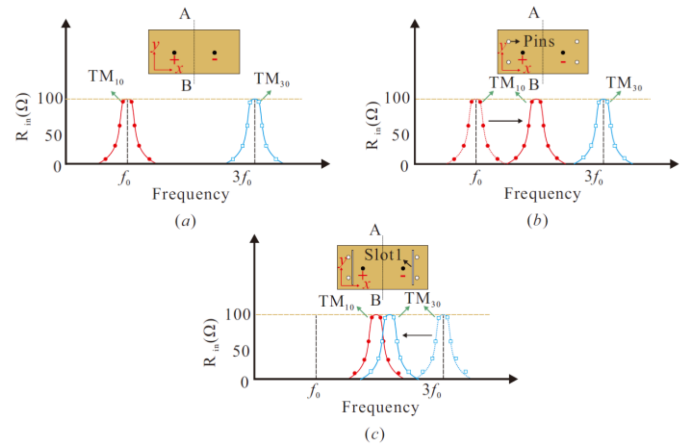


Fig. 4. Schematic of resonant frequencies of TM_{10} and TM_{30} modes in three distinctive differential-fed MPAs in [15]. (a) Conventional MPA. (b) MPA with shorting pins. (c) MPA with shorting pins and Slot1.

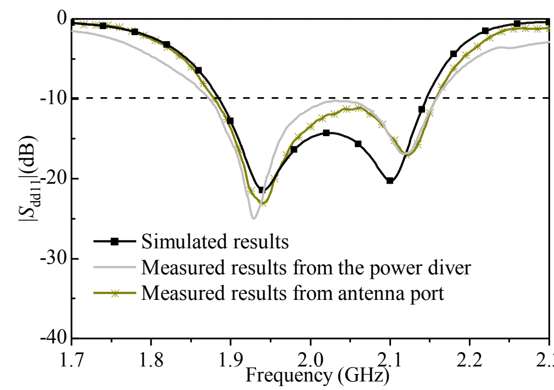


Fig. 5 Simulated and measured $|S_{dd11}|$ of the proposed differential-fed wideband MPA in [15] under dual-resonance.

influence on its overall thickness and radiation efficiency. As one of the most effective ways, a few resonant modes with equivalent radiative resistances, such as R_{10}, R_{12}, and R_{30}, are reallocated to resonate closely to each other. As reported in [15], the TM_{10} and TM_{30} modes shown in Fig. 4 are properly reallocated in proximity to each other by adding the shorting pins and slots. Hence, the Q_r of the antenna could be successfully decreased, leading to a widened bandwidth under multi-mode resonance. Thus, the impedance bandwidth ($|S_{dd11}|$ <-10 dB) of the antenna has gained a tremendous increment up to about 13% (1.88-2.14 GHz), while keeping a low profile property with the height of 0.029 free-space wavelength.

Although the MPAs in [14] and [15] have achieved a wide impedance bandwidth with a low profile property, they suffer from a high sidelobe of E-plane radiation patterns. Therefore, in the future work, the radiated fields of the low-profile wideband MPAs should be improved due to its high sidelobe level of E-plane radiation patterns at first. Besides, the electrical length of the radiating patch needs to be decreased so as to apply it in the low-profile array antenna design. Additionally, the beamwidth of the radiation patterns of the multi-mode antennas should be controlled and shaped in order to achieve the high gain or broad-bandwidth performances.

III. IN CONCLUSION

In this paper, the design concept about the bandwidth enhancement of the low-profile MPA by reallocating several radiative modes closely to each other is introduced. Firstly, the traditional wideband approaches have been performed for the MPA over the past two decades. The results show that the multi-mode technique of the MPA has the attractive low-profile property. After that, the working principle about how to achieve the wide-bandwidth for the antenna is extensively studied via the employment of several radiative resonant modes. Finally, a few future works about the multi-mode wideband antenna are further described.

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