Design on X-band Wideband and High-gain Microstrip Antenna

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Abstract

In this paper, a wide-band and high-gain microstrip antenna with double-layered microstrip patch and an aperture-coupled feeding is proposed. The simulated and measured results show that the relative impedance bandwidth is about 46.8% (VSWR≤2), front-to-back ratio better than 13 dB, and the gain is up to 8.3dB.

Keywords : Microstrip antenna Wide-band High-gain Aperture-coupled feed

1. Introduction

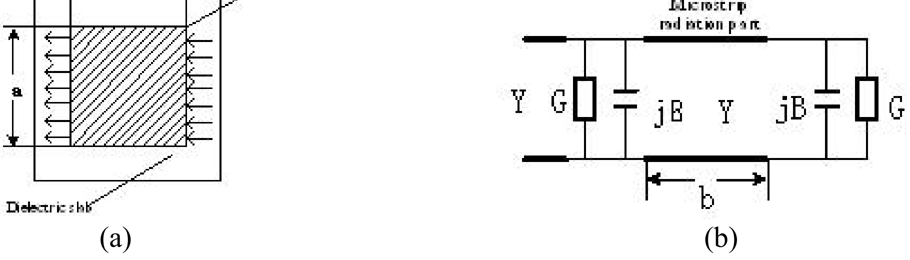
With the rapid development of modern Wireless Communication Technology, microstrip antenna is in researchers' good graces because of its advantages, such as low profile, light weight, compact and liable to produce[1]. However, the relatively narrow bandwidth of a microstrip is the major obstacle that restricts its wider usage in Wireless Communication system. By far, there are some methods that can broad the band width of Microstrip antennas. Literature [2] used the aperture coupled stacked patch antenna. The bandwidth of 50% is obtained. Using the proximity-coupled, the microstrip patch antenna can achieves an impedance bandwidth of 26% [3]. E-Shaped Microstrip Patch Antenna can be used. The bandwidth of 12.3% is obtained [4]. Some researches suggest the adoption of multilayer microstrip patch is a simple and effective method to achieve double resonance so as to broaden the bandwidth [5-10]. But the obvious defect is multilayer microstrip patch increases the profile thickness and volume of antenna. In this paper, the optimized design of antenna structure has broadened the bandwidth.

2. Analysis Approaches of Microstrip Antenna

The basic problem of antenna analysis is solving the created electromagnetic field by the antenna around it, and then educing the character key figure including radiation pattern, gain and input impedance. The essence theories of microstrip antenna analysis can be divided into three categories [11].

- Transmission line model ,TLM
- Cavity-model theory
- Integral equation method ,IEM, i.e. full-wave theory

In addition, GFM and MOM that arisen in recent years promoted antenna theories. Each theory possesses its strong points. The earliest and simplest approach of microstrip antenna analysis is Transmission line model. It is also the most appropriate one for currently engineering application. This paper will put the model into use. In this model, microstrip radiator element is considered as transmission line resonator with no horizontal field change. The field takes on a standing wave change along the length which is usually half wavelength. The radiation mainly produced by the fringing field of open circuit. The analysis of the microstrip patch antenna is shown in Fig 1(a), (b).



(a) (b)

Fig.1 Transmission line model and equivalent circuit of rectangle microstrip antenna.

The patch width a influences the directive function, radiation resistance and input resistance of the microstrip antenna. Then, the band width and the radiation efficiency are affected.

The patch width a is obtained by

$$a = \frac{c}{2 f_r}\left[\frac{\varepsilon_r + 1}{2}\right]^{-1/2} \tag{1}$$

The effect of edge scaling considered, resonance length b actually is obtained by

$$b = \frac{\lambda_0}{2\sqrt{\varepsilon_r}} - 2\Delta l = \frac{c}{2 f_r \sqrt{\varepsilon_e}} - 2\Delta l \tag{2}$$

Herein, the extension

$$\Delta l = 0.412h \frac{(\varepsilon_e + 0.3)(\frac{a}{h} + 0.264)}{(\varepsilon_e - 0.258)(\frac{a}{h} + 0.8)} \tag{3}$$

The effective permittivity

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + \frac{12h}{a})^{-1/2} \tag{4}$$

Where, C is the velocity of light. f_r is the resonance frequency of patch antenna. ε_r is the effective permittivity.

According to the Transmission line model, the radiation field of microstrip antenna is calculated by

$$E_\theta = A\cos\varphi\cos(\frac{k_0 b}{2}\sin\theta\cos\varphi)\bullet F_1(\theta,\varphi)\bullet F_2(\theta,\varphi) \tag{5}$$

$$E_\varphi = A\cos\theta\sin\varphi\cos(\frac{k_0 b}{2}\sin\theta\cos\varphi)\bullet F_1(\theta,\varphi)\bullet F_2(\theta,\varphi) \tag{6}$$

$$F_1(\theta,\varphi) = \frac{\sin(\frac{k_0 a}{2}\sin\theta\sin\varphi)}{\frac{k_0 a}{2}\sin\theta\sin\varphi} \tag{7}$$

$$F_2(\theta,\varphi) = \frac{\sin(\frac{k_0 h}{2}\sin\theta\cos\varphi)}{\frac{k_0 h}{2}\sin\theta\cos\varphi} \tag{8}$$

Where, $A = j\frac{2Va}{\lambda r'}e^{-jk_0 r'}$, r' signifies the distance from the center of microstrip patch to the field point. Due to $h \ll \lambda$, so $F_2(\theta,\phi) \approx 1$.

3. The Structure of Microstrip Antenna

The structure of antenna element is shown in Fig 2(a) 、Fig 2(b).The antenna is constituted by three dielectric slab and two-layered square radiation patch. The two patches are etched on the underside of the upper layer dielectric slab and the upside of the under layer dielectric slab. The earth plate and feeder are etched on the upside and underside of the bottom layer slab. The upper layer dielectric slab and the under layer dielectric slab is separated by air layer. The thickness of the air layer h=0.1λ0 [12]. The upper layer patch is fed and it determines the high point of the resonance frequency. The under layer is a passive coupling patch and it determines the low point of the resonance frequency. Modulated the degree of coupling in a certain range so as to differentiate the resonance frequency of the two patches and make each resonant bandwidth reciprocal chiasma. The overall bandwidth of the antenna is broadened. Simultaneously, the utilization of air layer is to decrease the Q factor of the antenna and broadens its bandwidth. The earth plate is etched by a diagonal cross slot which is in the superposition of the center of the radiation patch. The slot length and width greatly influences the resonance frequency and coupling degree of the antenna. On the condition that meets the requirement of operation bandwidth, the length and width of the slot should not be too long so as to avoid the backward radiation. By the way of adjusting the resonance length of antenna, its resonance frequency can be controlled. By changing the thickness of the air layer, the nominal coupling of the two patches can be modulated. By modifying the feeder width and tuner side length, the impedance match of antenna and the decrease of the frequency drift can be achieved. Then, the design of broadband antenna is realized.

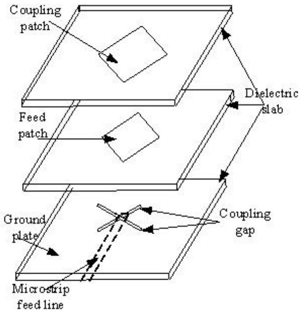


Fig.2(a) 3D Photograph of antenna structure

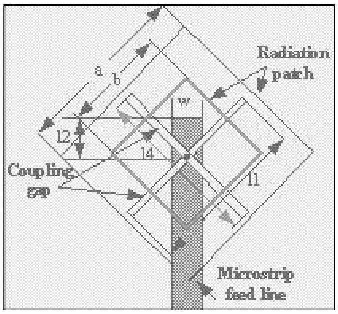


Fig.2(b) Platform of antenna structure.

4. Simulation and Measurement Results

Antenna model parameters: The side length of square-coupled patch is a=8.2mm, the side length of the radiation patch is b=7.2mm. The two dielectric slabs which adhered by the two patch is ε1=ε2=2.4, and the thickness of one slab is 0.5mm when another is 1.5mm. The thickness of dielectric feed board is 0.5mm and the dielectric constant is ε3=3.48. The width of the feed-line is 1.1mm, and the tuning length is l2=1.75mm. The width of the two coupling gaps is w1=w4=0.1mm and the length is l1=6mm and l4=7.5mm. The fabricated antenna is shown in Fig.3.

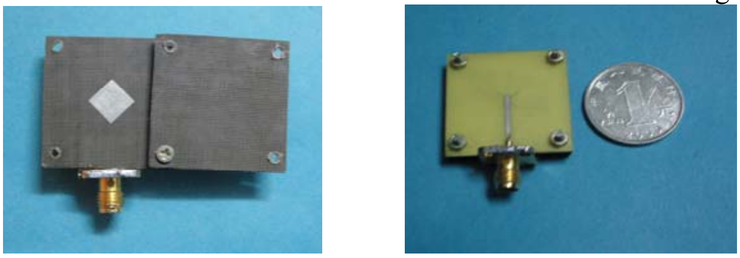
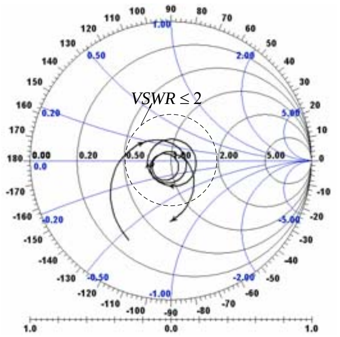


Fig.3 The fabricated antenna front view (left) and back view (right)

The input impedance is shown in Fig.4. The return losses of the antenna are shown in Fig.5. The antenna achieved a bandwidth of 46.8% where it operates from 8.47GHz to 13.65 GHz (S11≤ -10Db, VSWR≤2). Computed far-field radiation pattern for the antenna at 11 GHz is shown in Fig. 6. The antenna achieved a gain of 8.3dB.



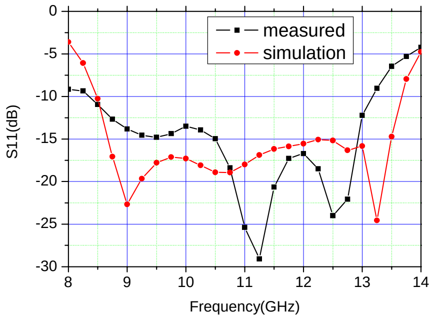


Fig.4 The smith charts of HFSS simulation for the antenna Fig.5 The input return loss of the antenna

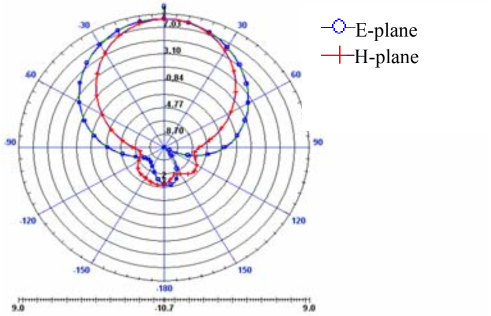


Fig.6 E-and H-planes radiation patterns of the antenna at 11GHz .

5. Conclusion

In this paper, an X-band multilayered planar microstrip antenna is presented. The antenna achieves extremely wide frequency bandwidth and good radiation characteristics in terms of beam pattern, front-to-back ratio. By simulation and measured the antenna demonstrated a bandwidth of 46.8% for a VSWR<2, front-to-back ratio better than 13 dB, a gain up to8.3dB. According to the results obtained, using the design method presented in this paper can extremely increase the impedance bandwidth of an X-band microstrip antenna. The method can be easily revised and extended for the design of other types of wide-band multilayered structures antennas.

References

[1] D. M. Pozar and D. H. Schaubert, Microstrip Antennas, New York: IEEE Press, 1995.

[2] S. D. Targonski and R. B. Waterhouse, An Aperture Coupled Stacked Patch Antenna with 50% Bandwidth, IEEE International Symposium on Antennas and Propagation, MD. 1996.

[3] S. Gao and A. Sambell, “A Simple Broadband Printed Antenna, Progress in Electromagnetics Research,” PIER 60, 119-130, 2006.

[4] B.-K. Ang and B.-K. Chung, “A Wideband E-Shaped Microstrip Patch Antenna for 5-6GHz Wireless Communications,” Progress in Electromagnetics Research, PIER 75, 397-407, 2007.

[5] R. Nilavalan, I. J. Craddock, A. Preece1, J. Leendertz1, R. Benjamin, “Wideband Microstrip Patch Antenna Design for Breast Cancer Tumour detection,” IEEE Trans. Microwave Theory and Techniques, vol. 48, no. 11, 1854-1863, 2000.

[6] K. S. Fong, H. F. Puse, M. J. Withers, “Wideband multilayer coaxial-fed microstrip antenna element,” Electron. Lett., vol. 21, no. 11, 497–499, 1985.

[7] Zhang-Fa Liu, Pang-Shyan Kooi, “A method for designing broad-band microstrip antennas in multilayered planar structures,” IEEE Transactions on Antennas and Propagation, vol. 47, no. 9, 1999.

[8] Zhang-Fa Liu, Pang-Shyan Kooi, Le-Wei Li, Mook-Seng Leong, Tat-Soon Teo, “A Method for Designing Broad-Band Microstrip Antennas in Multilayered Planar Structures,” Transactions on Antennas and Propagation, vol.47, no.9, 1416-1421, 1999.

[9] S.Gao, L.W.Li, M.S.Leong, T.S.Yeo, “A Broad-Band Dual-Polarized Microstrip Patch Antenna With Aperture Coupling,” Transactions on Antennas and Propagation, vol.51, no.4, pp.898-901, 2003.

[10] K.S.Fong, H.F.Puse, M.J.Withers, “Wideband multilayer coaxial-fed microstrip antenna element,” Electron. Lett., vol. 21, no. 11, 497-499, 1985.

[11] Kin-Lu Wong,Compact and broadband microstrip antennas, NewYork, A wiley-interscience publication 2002

[12] Prior C.J, Hall P.S, “Microstrip disc antenna with short-circruited annular ring,” Electron Lett., vol.21, 719-721, 1985.

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