Progress In Electromagnetics Research Letters, Vol. 2, 157–165, 2008

DESIGN OF SINGLE PIN SHORTED THREE-DIELECTRIC-LAYERED SUBSTRATES RECTANGULAR PATCH MICROSTRIP ANTENNA FOR COMMUNICATION SYSTEMS

A. Sharma and G. Singh

Department of Electronics and Communication Engineering
Jaypee University of Information Technology
Solan-173215, India

Abstract—In this paper, we have simulated a single-pin-shorted microstrip line fed three-dielectric-layer (with different permittivity and thickness) rectangular patch microstrip antenna for all those communication systems whose limited antenna size is premium. Low permittivity hard foam has been used as one substrate to achieve wide bandwidth. The simulation of this proposed antenna has been performed by using CST Microwave Studio, which is a commercially available electromagnetic simulator based on the finite difference time domain technique.

1. INTRODUCTION

A tremendous growth of the wireless RF identification (RFID) market is currently observed in the UHF and microwave frequency bands [1]. The microwave frequency range is also considered for electronic toll collection and more generally for wireless road-to-vehicle communication systems [2–5]. Microstrip antennas are one of the most innovative components which fulfill the requirements of all aforementioned communication systems, but the physical size of the patch conductor is too much large at UHF/microwave frequencies. For this reason, researchers have tried to develop techniques that reduce the surface area associated with the microstrip patch antenna. As the need for antenna size reduction, two major techniques, using a shorting post and high permittivity substrate material has been proposed. To decrease the resonant frequency of an antenna for a given surface area, the current path must be maximized within that area by the shorted patch concept. The high dielectric permittivity will also maintain the compactness of the structure whereas low dielectric permittivity will provide more efficient result. Bandwidth of the microstrip patch antenna can also be increased by increasing the thickness of the substrate material [6, 7]. The major disadvantage of increasing thickness is the reduced efficiency since the large portion of the input power is dissipated in the resistor which takes away the available power that can be radiated by antenna. Further more, reducing the height of the structure may appear to be a suitable solution, but it may lead to a reduced impedance bandwidth and lower radiation efficiency. This is often a tradeoff in realizing compact antennas while maintaining performance characteristics. The advantage of loading very high permittivity material for microstrip patch antenna compared to the shorting pin is the elimination of the need for a shorting post to penetrate through the substrate, hence making the device easier to manufacture.

The high permittivity substrate has a poor choice for antenna bandwidth, since the bandwidth of a microstrip antenna is best for low dielectric constant substrates and if substrate thickness is increased in an attempt to improve bandwidth, spurious feed radiation increases and surface wave power increases. As a patch antenna radiates, a portion of the total available power for direct radiation becomes trapped along the surface of the substrate. This trapped electromagnetic energy leads to the development of surface waves. In fact, the ratio of power that radiates into the substrate compared to the power that radiates into air is approximately ($\varepsilon^{3/2}$: 1). The power launched into the surface waves is power which will eventually be lost, hence the excitation of surface waves lowers the overall radiation efficiency of the antenna. The surface waves are spread out in a cylindrical fashion around the excitation point with field amplitudes decreasing with distance. They are incident on the ground plane, get reflected from there and then meet the dielectric-air interface, which also reflects them. Following this zigzag path, they finally reach the boundaries of the microstrip structure where they are reflected back and diffracted by edges giving rise to end-fire radiation.

For microstrip patch antennas, reduction in thickness of substrate, in general, will lower the efficiency and bandwidth. In this paper, we have proposed a single-pin-shorted three-dielectric layer substrate rectangular patch antenna to improve the radiation efficiency and bandwidth without sacrificing, the cost and operational advantages. The design of this proposed microstrip antenna is based on the philosophy of maximizing the current path for a given surface area to decrease the resonant frequency by shorting post and use three-layer substrate material to reduce the radiation losses by surface waves [8–12] to improve the efficiency. The selection of the dielectric permittivity and dimension of the substrates will determine the surface wave losses. The organization of the paper is as follows. The Section 2 is concerned with the proposed antenna configuration. The Section 3 discusses the simulated results. Finally, Section 4 concludes the work.

2. ANTENNA CONFIGURATION

The geometrical configuration of the proposed rectangular patch microstrip antenna is shown in Fig. 1. The dimension of the ground plane of the antenna is $30 \times 30\,\mathrm{mm}^2$. The rectangular patch has width and length as 10 mm and 17.15 mm, respectively. The substrate material of the antenna is arranged as follows. The first substrate layer on ground plane of thickness 0.787 mm is RT/Duroid5880 ($\varepsilon_1 = 2.42$) with $\tan\delta = 0.0009$. This layer is followed by hard foam of 12.7 mm thickness with dielectric constant $\varepsilon_2 = 1.07$ and last layer with 1.27 mm thick RT/Duriod6006 ($\varepsilon_3 = 6.15$) with $\tan\delta = 0.0019$. A hard foam layer has been used between two substrate layers to achieve wide bandwidth. The reason to take high dielectric constant (upper layer) is to reduce the radiation loss from the feed line and thin substrate material has been used for maximizing the bandwidth [13]. By properly choosing substrate parameters, a significant increase

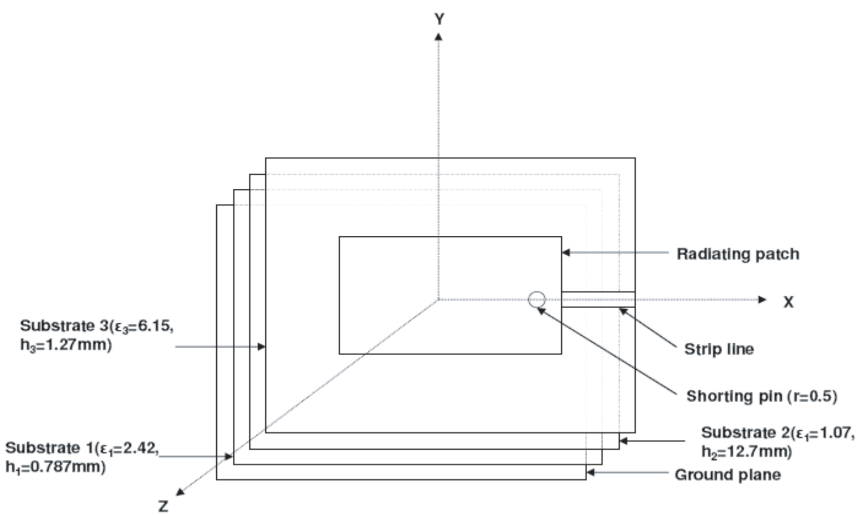

Figure 1. The geometrical configuration of the three-dielectric-layer substrate microstrip line fed rectangular patch microstrip antenna.

in impedance bandwidth, radiation resistance and efficiency may be achieved. When the high relative permittivity substrate is over the low relative permittivity substrate, the suppression of the surface wave will happen. Due to this efficiency will increase. The shorting pin with a diameter of 0.5 mm is loaded at the radiating end of rectangular patch. This loading position can ensure maximum reduction in the resonant frequency of the microstrip antenna that is maximum patch size reduction for the antenna can be obtained at a fixed frequency. Microstrip line feed which has been used in the proposed antenna is one of the most commonly used feeding techniques. Since feeding technique influences the input impedance, it is often exploited for matching purpose. In this feeding technique, a conducting strip is connected directly to the edge of the rectangular patch microstrip antenna. The advantage of this technique is that both the feed and patch lie on the surface of the substrate and therefore is plane in construction and provide the right impedance match between the patch and feed line [14, 15]. Since the input impedance of the patch gradually decreases from maximum at the edge (150 to 300 Ω) to minimum at the center. The impedance matching associated with this class of antennas are also simpler compared to other methods. This technique is efficient on thin substrate; thick substrate should be avoided as they could result in spurious feed radiation and cross polarization effects [16].

3. RESULTS AND DISCUSSION

Using high dielectric constant materials has been proposed [17–19], however, so far, only poor efficiency due to surface wave excitation and narrow bandwidth have been achieved. Also, the limited availability of low cost, low loss, high dielectric constant material is another problem with this method. It is well known that for the case of conventional single layered microstrip antenna, the gain decreases with the increase in dielectric constant. Another effective way to reduce the antenna size is to use a shorted quarter wavelength patch. It is important to note that at a fixed frequency, the patch size can be increased or decreased, depending on the distance of the shorting post from the feed. In proposed antenna configuration, we have considered the concept of shorting post and three-dielectric layer substrate material to increase the bandwidth and efficiency for miniaturized dimension. It is clearly seen that, for the short-circuited patch antenna, the input impedance become very sensitive to the feed position and strongly depends on the distance between the shorting pin and the feed position. For reasonable bandwidths, thick foam substrate has been used. The use of an electrically thick substrate reduces the dimension of the patch conductor and increases the separation distance between the feed points and shorting posts results the increase in the inductance [20]. With this approach, we achieved very large 10 dB impedance bandwidth as shown in Fig. 2. The return loss of the proposed rectangular patch antenna at frequency 4.591 GHz is approximately −38 dB, which is very good result as shown in Fig. 2. The strong dependence of the input impedance on the close positioning of the shorting post with respect to feed and narrow impedance bandwidth as shown in the Fig. 2.

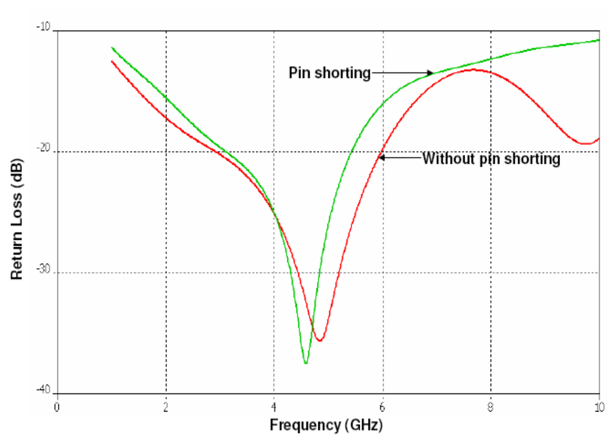

Figure 2. Return losses versus frequency for single shorting pin rectangular patch antenna on three dielectric substrate layers.

The E-plane and H-plane radiation pattern at this resonant frequency (4.591 GHz) is also shown in Fig. 3. The radiation efficiency and gain of the proposed microstrip antenna are approximately 93% and 1.639 dB, respectively.

The diameter of the shorting post and the separation distance between the feed point and shorting post also play an important role in the overall size of the patch conductor. Basically, the shorting post is modeled as an inductance parallel to the resonant LC circuit describing a reference resonant mode of the unloaded (without shorting post) patch. In an equivalent circuit, new resonance mode (with shorting post) can be viewed as resulting from the inductance (due to shorting post) in series with static capacitance of the patch configuration. Larger the inductive part, smaller will be the resulting resonance frequency, that is, the larger will be the degree of miniaturization achieved for a fixed operating frequency. We have optimized the diameter of the shorting pin for lowest resonant frequency and

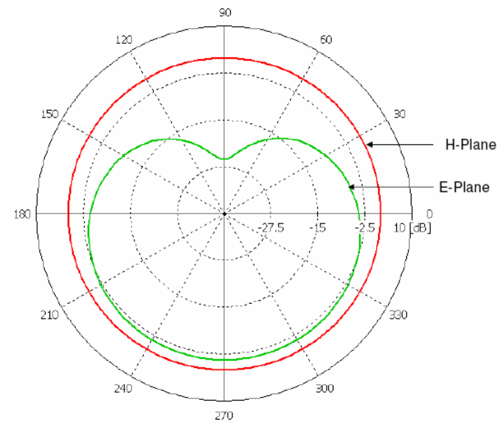

Figure 3. E and H plane far field pattern of gain at frequency 4.591 GHz.

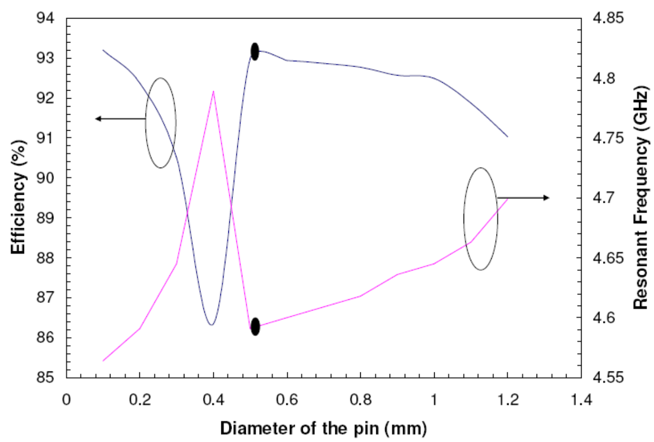

Figure 4. Variation of the resonant frequency and radiation efficiency of the proposed microstrip antenna versus the diameter of the shorting pin.

maximum radiation efficiency as highlighted by the dark spot in the Fig. 4.

A determination of all relevant parameters for the shorting post microstrip antenna is straight forward once the resonant frequency has been determined. It has been shown that the resonant frequency depends critically on the position and dimension of the shorting post. At a fixed frequency, the shorted patch size can be increased or decreased, depending on the distance of the pin from the feed as shown

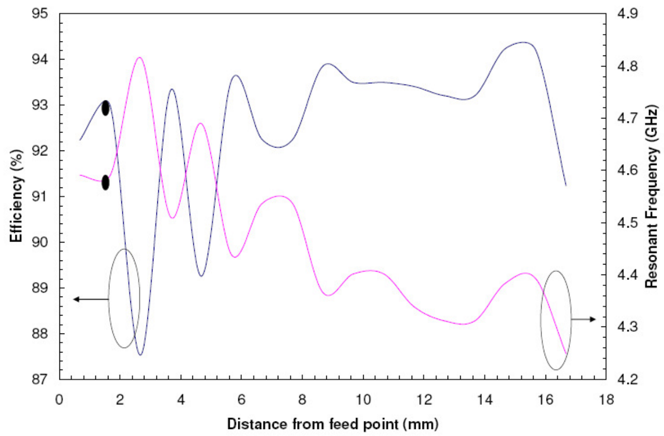

Figure 5. Variation of the resonant frequency and radiation efficiency versus the distance of pin from feed point.

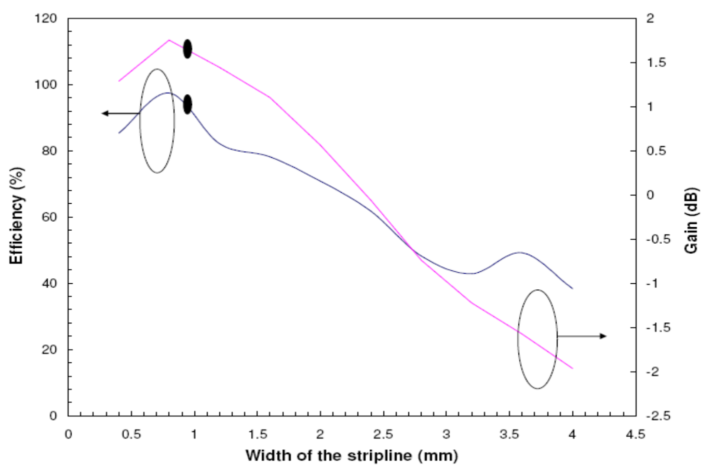

Figure 6. Variation of efficiency and gain with width of the microstrip feed line.

in Fig. 5. Therefore, for a single shorting pin antenna, accuracies of a fraction of a millimeter are required for close positioning between the feed and the shorting pin. The distance from the feed point in proposed simulation is 1.675 mm. At this point, we will optimize radiation efficiency at lower resonant frequency as highlighted in Fig. 5.

In the Fig. 6, we have simulated the effects of the width of microstrip line used for feeding the proposed antenna structure.

Maximum gain and efficiency are obtained at 1 mm width of the strip-line as highlighted in Fig. 6. There is a continuous decrease in efficiency and gain as the width of the strip line increases.

4. CONCLUSION

An optimum design for a broadband small microstrip antenna is presented. The microstrip line fed pin shorted three-layer substrate rectangular patch antenna shows significant size reduction and highest bandwidth. Due to its compactness and broadband operation, more applications for the single pin-shorted patch antenna can be anticipated. With this approach, we achieved very high 10 dB bandwidth. The gain and radiation efficiency of the proposed rectangular patch antenna at frequency 4.591 GHz are approximately 1.639 dB and 93%, respectively, which are good.

REFERENCES

1. Ang, B. K. and B.-K. Chung, "A wideband E-shaped microstrip patch antenna for 5–6 GHz wireless communication," *Progress In Electromagnetics Research*, PIER 75, 397–407, 2007.
2. Aissat, H., L. Cirio, M. Grzeskowiak, J.-M. Laheurte, and O. Picen, "Reconfigurable circularly polarized antenna for short-range communication systems," *IEEE Trans. Microwave Theory Techniq.*, Vol. 54, 2856–2863, 2006.
3. Hirvonen, M., P. Pursula, K. Jaakkola, and K. Laukkanen, "Planar inverted-F antenna for radio frequency identification," *Electron Lett.*, Vol. 40, 848–850, 2004.
4. Geyi, V., Q. Rao, and D. Wang, "Handset antenna design: Practice and theory," *Progress In Electromagnetics Research*, PIER 80, 123–160, 2008.
5. Abbaspour, M. and H. R. hassani, "Wide band star shaped microstrip patch antennas," *Progress In Electromagnetics Research Letters*, Vol. 1, 61–68, 2008.
6. Abdelaziz, A. A., "Bandwidth enhancement of microstrip antenna," *Progress In Electromagnetics Research*, PIER 63, 311–317, 2006.
7. Nishiyama, E. and M. Aikawa, "FDTD analysis of stacked microstrip antenna with high gain," *Progress In Electromagnetics Research*, PIER 33, 29–43, 2001.

8. Xia, L., C.-F. Wang, L.-W. Li, P.-S. Kooi, and M.-S. Leong, "Resonant behaviors of microstrip antenna in multilayered media: An efficient full wave analysis," *Progress In Electromagnetics Research*, PIER 31, 55–67, 2001.
9. Harokopus, W. P. and P. B. Katehi, "Characterization of microstrip discontinuities on multilayer dielectric substrates including radiation losses," *IEEE Trans. Microwave Theory Tech.*, Vol. 37, 2058–2066, Dec. 1989.
10. Tsai, M. J., F. D. Flaviis, O. Fordham, and N. G. Alexopoulos, "Modeling planar arbitrarily shaped microstrip elements in multilayered media," *IEEE Trans. Microwave Theory Tech.*, Vol. 45, 330–337, Mar. 1997.
11. Schwab, W. and W. Menzel, "On the design of planar microwave components using multilayer structures," *IEEE Trans. Microwave Theory Tech.*, Vol. 40, 67–72, Jan. 1992.
12. Yeung, E. K. L., J. C. Beal, and Y. M. M. Antar, "Multilayer microstrip structure analysis with matched load simulation," *IEEE Trans. Microwave Theory Tech.*, Vol. 43, 143–149, Jan. 1995.
13. Eldek, A. A., "Numerical analysis of a small ultra wideband microstrip FED tap monopole antenna," *Progress In Electromagnetics Research*, PIER 65, 59–69, 2006.
14. Lo, T. K., C.-O. Ho, Y. Hwang, E. K. W. Lam, and B. Lee, "Miniature aperture-coupled microstrip antenna of very high permittivity," *Electron. Lett.*, Vol. 33, 9–10, Jan. 1997.
15. Zhang, G.-M., J.-S. Hong, and B. Z. Wang, "Two novel band-notched UWB slot antennas fed by microstrip line," *Progress In Electromagnetic Research*, PIER 78, 209–318, 2008.
16. Yang, S. L. S., K. F. Lee, and A. A. Kishk, "Design and study of wideband single feed circularly polarized microstrip antenna," *Progress In Electromagnetic Research*, PIER 80, 45–61, 2008.
17. Waterhouse, R. B., S. D. Targonski, and D. M. Kokoto, "Design and performance of small printed antennas," *IEEE Trans. Ant. Prop.*, Vol. 46, 1629–1633, 1998.
18. Waterhouse, R. B., "Small microstrip patch antenna," *Electronics Letters*, Vol. 31, 604–605, 1995.
19. Kan, H. K. and R. B. Waterhouse, "Size reduction technique for shorted patches," *Electronics Letters*, Vol. 35, 948–949, 1999.
20. Porath, R., "Theory of miniaturized shorting post microstrip antennas," *IEEE Trans. Antennas Propag.*, Vol. 48, No. 1, 41–47, Jan. 2000.