Performance Analysis of Wearable Microstrip Antennas with Low-Conductivity Materials

Erdem Yilmaz* (1), Dayalan P. Kasilingam(1), and Branislav M. Notaros(2)
(1) Department of Electrical and Computer Engineering
University of Massachusetts Dartmouth, North Dartmouth, MA, USA
(2) Department of Electrical and Computer Engineering
Colorado State University, Fort Collins, CO, USA
E-mail: eyilmaz@ieee.org

Introduction

In recent years, with the development of applications in personal communication technologies, wearable antennas have received growing attention [1]. It is anticipated that in the near future, a wide variety of consumer electronics and communication devices will be wearable – built into clothing. Accordingly, textile-based wearable antennas are foreseen as a major component of wearable electronics in emerging personal communication systems.

Conventional wearable antennas are studied and constructed with metallic elements, which can be treated as perfect electric conductors [2], [3]. However, recent advances in material sciences have given rise to electronic devices in which conducting materials in the form of ink are printed on various surfaces [4]. In our research, in order to enhance the flexibility, weight, and conformity of wearable designs, carbon nanostructured conductor inks and conducting polymer inks are proposed and studied as possible conductors in textile-embedded wearable antennas. Since the conductivity of these inks is not high enough for the material to be treated as perfectly conducting, the principal scope of this study is the design, characterization, and development of wearable microstrip antennas with low conductivity materials. In specific, a 2.4-GHz WLAN rectangular microstrip textile antenna design is presented, with low conductivities of the patch and ground materials. Both impedance and radiation properties of the antenna are studied. Numerical results and discussion are based on using two independent commercial electromagnetic tools for antenna modeling and analysis.

Antenna Model

In this study, CST Microwave Studio™ and Ansoft HFSS™ are used for the analysis of the antennas. The substrate material is assumed to be lossless, with a dielectric constant of $\varepsilon_r = 2.2$. As the antenna structure is required to be thin for wearable applications, the substrate thickness is adopted to be 1.5 mm. In addition, due to a delicate nature of conductor ink implementations, it may not be

---

This work was supported by the National Textile Center under Grant M06-MD01.

978-1-4244-2042-1/08/$25.00 ©2008 IEEE

appropriate to excite a patch made of conductor polymer by directly connecting the metallic feed to it. Therefore, the patch is fed by a 50-Ω microstrip transmission line, with a quarter-wave microstrip transformer inserted to match the antenna impedance to 50 Ω, as shown in Figure 1. The ground conductor is adopted to be three times as large as the patch [5].

The antenna is first designed for the case of all conductors in the structure being made of copper, and the optimum dimensions of the structure, obtained with a series of simulations, are given in Table 1. The conductivity of the patch, transmission lines, and ground is then substantially decreased to model and investigate the performance of the antenna with non-metallic conductors, and to ultimately identify the low-conductivity limit for practical microstrip antenna implementations.

Results and Discussion

Figure 2 shows the simulated results for the antenna impedance and radiation pattern for conductivities $\sigma_1 = 5.7\times10^7$ S/m (copper), $\sigma_2 = 5.7\times10^5$ S/m, and $\sigma_3 = 5.7\times10^3$ S/m, respectively, of all conductors in the structure. We observe from the figure, that, while the matching properties of the antenna (with respect to 50 Ω) appear to be even better for the conductivity value σ_2 than for σ_1, they are severely degraded by reducing the conductivity to σ_3. We may say that this level of conductivity makes the antenna impractical in terms of its low received power.

The presented results for the antenna gain, which accounts for conductor losses in the conductors but not for mismatch losses at the port [6], generated by varying θ for $\varphi = 0$ in Figure 1, show similar trends. For copper conductors, the gain pattern is nearly symmetric with respect to the direction defined by $\theta = 0$, and has a peak value of 7.3 dB (using both simulation tools). For the conductivity σ_2, both the pattern symmetry and the gain peak value (6 dB) are slightly reduced, but still are acceptable for wearable microstrip antenna applications. However, the antenna gain levels for the conductivity σ_3 drop to practically unacceptable values, due to very large conductor losses.

Conclusions

This paper has presented a 2.4-GHz WLAN rectangular microstrip textile antenna design, along with investigations of the degradation in resonant, matching, and gain properties of the antenna if low conductivity materials are used for all conductors in the structure. The results show that the resonant frequency remains almost the same for lower conductivities, and that the reflection from the antenna port is even smaller for conductivities on the order of 10^5 S/m than for copper conductors, the mismatch losses increase to prohibitive levels for conductivities on the order of 10^3 S/m. The antenna gain attains reasonable values for $\sigma \sim 10^5$ S/m. However, for conductors with $\sigma \sim 10^3$ S/m, the conductor losses dominate the radiated power, resulting in practically unacceptable gain levels. Overall, conductivity levels of WLAN microstrip textile antennas must be in excess of $\sim 10^4$ S/m for an acceptable antenna performance in wearable applications.

References

[1] C. Cibin, P. Leuchtmann, M. Gimersky, R. Vahldieck, and S. Moscibroda, "A flexible wearable antenna," *Proc. of IEEE Antennas and Propagation Society International Symposium*, vol. 4, pp. 3589-3592, Monterey, CA, USA, June 2004.

[2] P. Salonen and H. Hume, "A novel fabric WLAN antenna for wearable applications," *Proc. of IEEE Antennas and Propagation Society International Symposium*, pp. 700-703, Columbus, OH, USA, June 2003.

[3] P. Salonen, L. Sydanheimo, M. Keskilammi, and M. Kivikoski, "A small planar inverted-F antenna for wearable applications," *3rd Int. Symposium on Wearable Computers Digest*, pp. 95-100, San Francisco, CA, USA, October 1999.

[4] B. J. de Gans, P. C. Duineveld, and U. S. Schubert, "Inkjet Printing of Polymers: State of the Art and Future Developments," *Advanced Materials*, vol. 16, issue 3, pp. 203-213, 2004.

[5] V. Natarajan, E. Chettiar, and D. Chatterjee, "Effect of ground plane size on the of a class of microstrip antennas on microwave substrates", *Proc. of IEEE Antennas and Propagation Society International Symposium*, vol. 4, pp. 4491-4494, Monterey, CA, USA, June 2004.

[6] C. A. Balanis, *Antenna Theory Analysis and Design*, John Wiley & Sons, 1997.

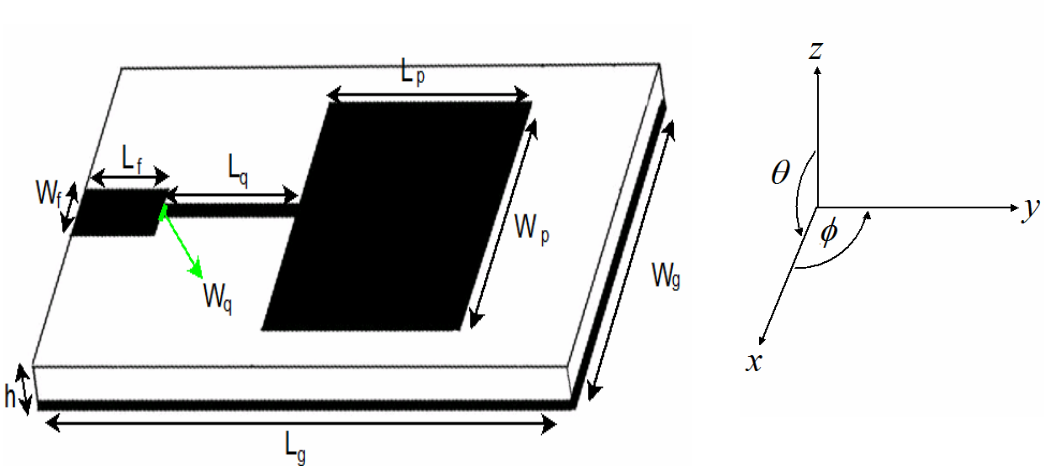
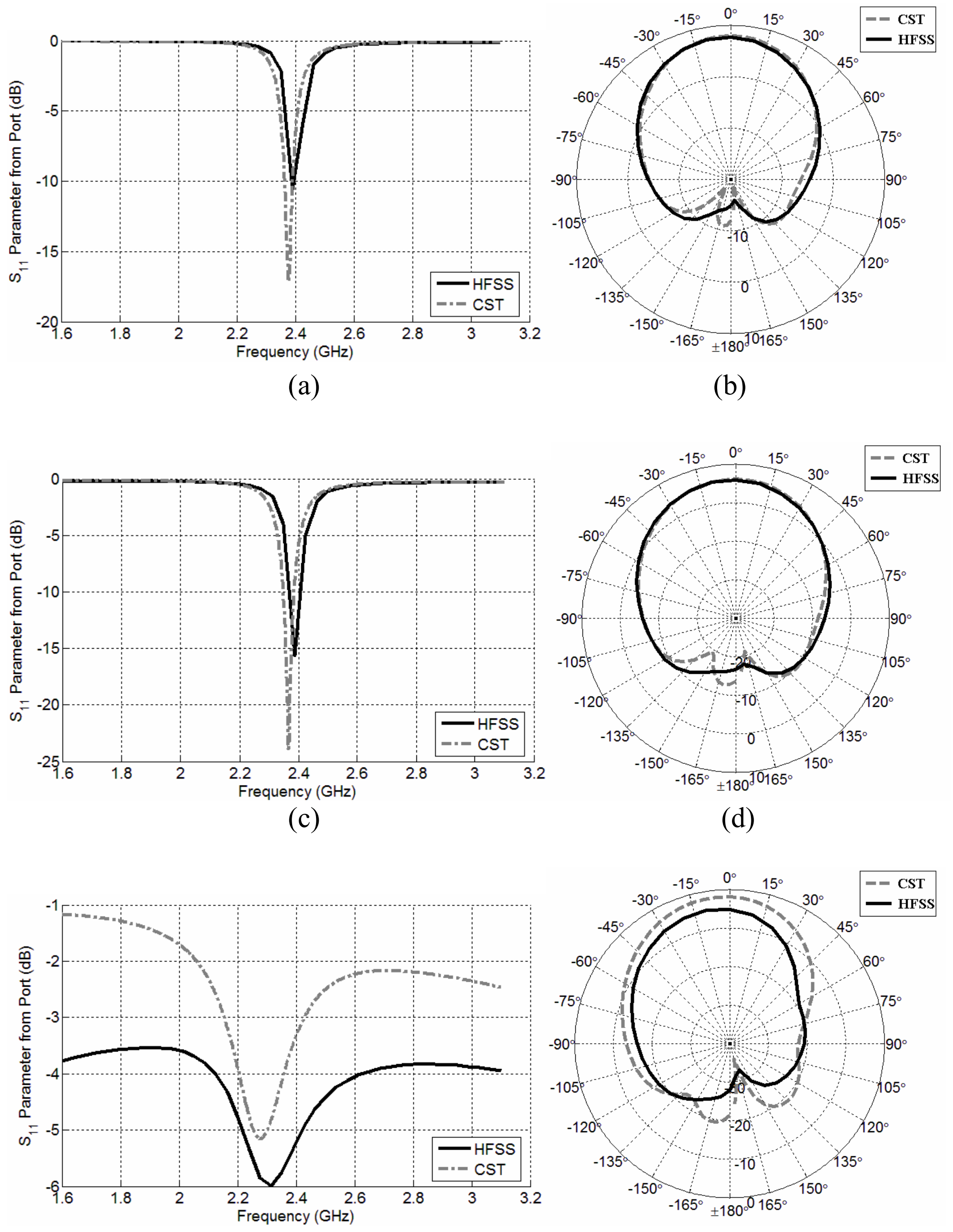


Figure 1: 2.4-GHz WLAN rectangular microstrip textile antenna with low-conductivity materials for all conductors ($\varepsilon_r = 2.2$ for the substrate).

Table 1: Dimensions (in mm) of the designed antenna in Figure 1.

W_p	L_p	W_q	L_q	W_f	L_f	W_g	L_g	h
42	40.5	0.72	21.05	4.84	19.45	126	121.5	1.5



(a) (b)

(c) (d)

(e) (f)

Figure 2: Simulated results (using CST Microwave Studio™ and Ansoft HFSS™) for S_{11} (reference 50 Ω) and gain (in the plane $\varphi = 0$) of the microstrip antenna in Figure 1 (dimensions in Table 1) for conductivities $\sigma_1 = 5.7\times10^7$ S/m (copper) (a)-(b), $\sigma_2 = 5.7\times10^5$ S/m (c)-(d), and $\sigma_3 = 5.7\times10^3$ S/m (e)-(f), of all conductors in the structure.