

# Radiation Efficiency Measurements of Embroidered Textile Radiating Elements Placed in the Vicinity of a Human Equivalent Phantom

Hiromichi Nomura and Tadahiko Maeda

Graduate School of Information Science and Engineering at Ritsumeikan University  
1-1-1 Nojihigashi, Kusatsu, Shiga, 525-8577, Japan

**Abstract** - In assessing the embroidered conductive yarn textile antennas, which are commonly used in the vicinity of a human body, it is important to assess the following two types of loss: 1) the loss caused by a human body, and 2) the loss caused by a conductive yarn. The sewing pattern of radiating elements affects the plasticity, flexibility and texture of the embroidered antenna. Also, the sewing pattern affects the radiation efficiency of the antenna. This paper presents the measured radiation efficiencies of full and partially embroidered textile dipole antennas with different sewing patterns. The proposed partially embroidered antennas (Model A and Model B) with current-distribution-based sewing patterns can reduce the amount of conductive yarn by 80% and 91%, respectively. The difference in the measured radiation efficiency between the Model A antenna and the same sized copper reference antenna was 1 – 12% when the antennas were placed in the vicinity of a phantom.

**Index Terms** — Wearable antennas, textile antennas, conductive yarn, human body, radiation efficiency, radiating element.

## 1. Introduction

An embroidered textile-radiating element is one of the most important key components to realize the cloth-embedded wearable antennas for Body-Area Network (BAN). The loss caused by a human body varies depending on the distance between the antenna and a human body, which is the primary factor for the deterioration of the antenna's radiation efficiency [1] [2].

Wearable antennas are commonly fabricated using conductive yarns whose conductivities are much smaller than that of copper wires. Thus, the characteristics of embroidered antennas must be evaluated by including the loss caused by conductive yarns [3] [4]. When embroidered antennas are embedded into the clothes, the sewing pattern of radiating elements affects the plasticity, flexibility, and texture of the embroidered antenna. Thus, the trade-off between those factors and the radiation efficiency of the antenna is important.

In this paper, a textile embroidered dipole antenna has been selected to assess the radiation efficiencies for several sewing patterns of the embroidered radiating element in

order to evaluate the off-body and on-body performance of a textile embroidered dipole antenna.

## 2. Basic antenna structure

Fig. 1 shows the geometry of the embroidered textile antennas. All the embroidered antennas assessed in this study were fabricated on a flexible substrate with the conductive yarns for bobbin thread and polyester thread for upper thread by a computerized sewing machine. The flexible substrate was a commercially available felt fabric ( $\epsilon_r$ : 1.3,  $\tan \delta$ : 0.0045) with a thickness of 1.0 mm.

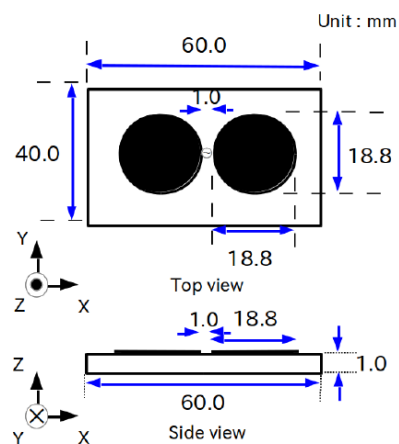


Fig. 1. Antenna structure.

## 3. Embroidered radiating elements

### (1) Sewing patterns

Two proposed partially embroidered textile dipole antennas (Model A and Model B) with different sewing patterns were fabricated based on the calculated results of the current distribution for the copper antenna with the dimensions shown in Fig. 1.

These two models are shown in Fig. 3 and can reduce the amount of conductive yarn by 80% and 91%, respectively compared to that of the full embroidered radiating element as shown in Fig. 3.

## (2) Radiation efficiencies without a phantom

The antennas were excited through a hybrid coupler and the inner conductors of two coaxial cables were connected to each side of the feed point. The antennas under test were measured to assess the relative radiation efficiency by the relative radiation efficiency measurement method [5] using a radiation efficiency standard. The standard antenna was the same-sized copper reference antenna. Fig. 4 shows the measured off-body radiation efficiencies for different sewing patterns.

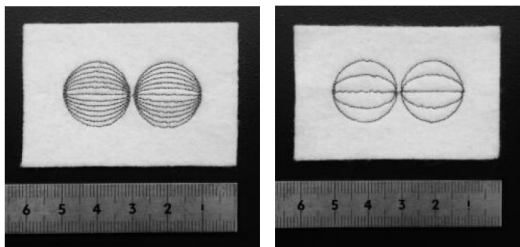


Fig. 2. Partial-embroidered Models: Model A and Model B.



Fig. 3. Full-embroidered Model: Close up photo of the half side of the radiating element.

The difference in the measured radiation efficiencies between the full embroidered Model and Model A antenna was about 8%. This difference was about 15% for the proposed sewing pattern in Model B.

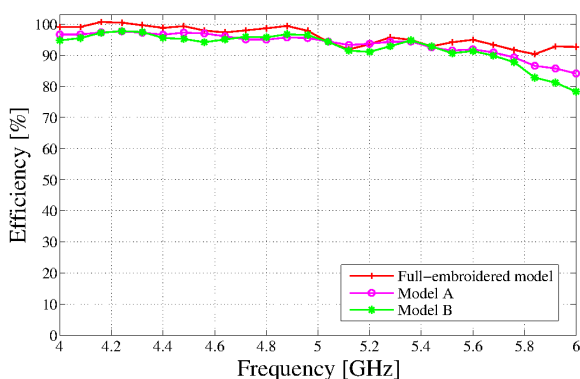


Fig. 4. Measured radiation efficiencies.

## (3) Radiation efficiencies with a phantom

Fig. 5 shows the measured on-body radiation efficiencies for three embroidered radiating elements as well as for the reference copper radiating element. During measurements, all radiating elements were placed in the vicinity of a 2/3 human muscle equivalent phantom whose dimensions are  $150 \times 100 \times 50$  mm under the condition of 10 mm spacing

between the antenna and the phantom. The difference in the measured radiation efficiencies between the Model B antenna and the same sized copper reference antenna was 1 – 12% when the antennas were placed in the vicinity of the phantom.

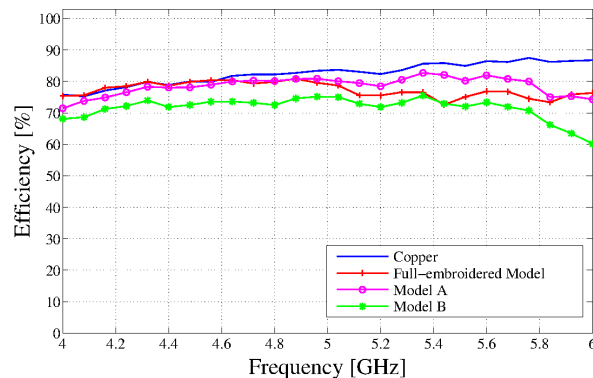


Fig. 5. Measured on-body radiation efficiencies

## 4. Conclusion

The radiation efficiencies of proposed antennas with different sewing patterns based on the calculated results of the current distribution were experimentally evaluated both with and without the human equivalent phantom. Compared to the full-embroidered sewing pattern, the proposed partial-embroidered sewing pattern in Model B, which can reduce the amount of the conductive yarn by about 80%, demonstrated similar on-body radiation efficiency performance.

## Acknowledgment

A part of this study was conducted with funding from a Grant-in-Aid for Scientific Research (Basic research (B) 26289122) from the Japan Society for the Promotion of Science.

## References

- [1] S.J. Boyes, P.J. Soh, Y. Huang, G.A.E. Vandenbosch, and N. Khiabani, "Measurement and performance of textile antenna efficiency on a human body in a reverberation chamber," *IEEE Trans. Antennas and Propagation*, vol. 61, no. 2, pp. 871-881, 2013.
- [2] T. Yoshikawa, T. Maeda, "Characteristics on an Embroidered Conformal Wideband Flexible Slot Antenna," *Proc. International Microwave Workshop on Electromagnetics (iWEM2015)*, Taipei, Taiwan, TUA 1.2, Nov. 2015.
- [3] Yu Ping Hung, "Effect of Sewing Types on Flexible Embroidery Antennas in UHF Band," *European Microwave Conference 2013*, pp. 88-91, 2013.
- [4] S. Zhang, A. Chauraya, W. Whittow, R. Seager, T. Acti, T. Dias, and Y. Vardaxoglou, "Embroidered wearable antennas using conductive threads with different stitch spacings," *Proc. Loughborough Antennas Propag. Conf.*, 2012.
- [5] K. Fujimoto, K. Asanuma, T. Wakabayashi, and T. Maeda, "Scale-model Experiments on Impedance and Radiation Efficiency Measurements Using Scale-model Human Equivalent Phantoms Placed in the Vicinity of the Antenna Under Test," *IEICE Technical Report, AP2008-83*, pp.49-54, Sept. 2008.