Three types of Radiating Element for UWB Antennas Placed in the vicinity of a Human Finger

Daisuke Ushirogochi[1, 2], Kenichi Asanuma[1], and #Tadahiko Maeda[1]
[1]Graduate School of Science and Engineering, Ritsumeikan University
1-1-1 Nojihigashi Kusatsu Japan 525-8577, tmaeda@ieee.org
[2] Current affiliation: Omron Corporation

1. Introduction

The field of wearable computing has received considerable global attention in recent years, and within the area of wireless communication systems, Wireless Personal Area Networks (WPAN) and Wireless Body Area Networks (WBAN) have been the focus of considerable research, including various types of antennas for these applications [1] - [3]. This paper describes the basic characteristics of three types of radiating element for UWB antennas placed in the vicinity of a human finger and proposes a ring-type lower radiating element for UWB antennas.

2. Antenna structures and calculated results

This paper assumes a communications environment consisting of a finger-mounted wearable terminal as a mode of use, as shown in Fig. 1. The analytical model, where the finger was considered isolated as shown in Fig. 2, was selected as an initial set-up orientation of the radiating element for a finger mounted wearable handset and a tubular model of the human finger, comprising the three layers of skin, muscle, and bone, was employed. The frequency dispersion for the complex dielectric constant of skin and muscle, being comparatively large, is approximated with the Debye dispersion, and implemented using the piecewise linear recursive convolution (PLRC) method.

Figure 3 shows the calculated radiation efficiency for the analytical model shown in Fig. 2 when the distance D between the antenna and finger was increased from 1 mm to 5 mm in 1 mm increments. It is apparent that the radiation efficiency (Efficiency=Radiated power/Input power) is almost uniformly reduced over a wide frequency range (From 7 GHz to 11 GHz) by approximately 10 % for each 1 mm reduction in distance between the antenna and finger. Furthermore, as the lower frequencies are reached, radiation efficiency decreases dramatically. While the minimum radiation efficiency of 50 % can be achieved when the distance is 5 mm, the direction of the main radiation is perpendicular to the required beam direction (axial direction of the finger) as a pointing device. Also, the results for input impedance reveal that the larger the distance between the antenna and the finger, the greater the variations in both resistance and reactance, as shown in Fig. 4.

In order to improve radiation efficiency, especially in the lower frequency range in the UWB band as well as the stable input impedance characteristics, multiple shapes of radiating element shown in Fig. 5 were evaluated; where the distance between the antenna and finger was 3 mm for Model A considering the trade-off between the radiation efficiency and input impedance. Model B has Model A’s radiating element bent at 90 degrees, in order to suppress the radiation into the finger, while Model C has a ring-shaped lower element.

The input impedance and VSWR characteristics are shown in Figs. 6 and 7 respectively, with the most stable input impedance characteristics observed for Model C in terms of both resistance and reactance. While Models B and C show similar radiation efficiency characteristics, the input impedance characteristics of Model C are much better than those of Model B, as shown in Fig. 6. It has also been concluded that the effectiveness of the ground element structure (ring-shaped lower element) for Model C is superior to the original ground element structure for Model B , due to the encircled particular structure for the ring-shaped lower element of Model C. Since the input resistance of the elliptical disk dipole antenna is near 100 ohms, the characteristic impedance of the transmission line for VSWR calculation in Fig. 7 is selected at 100 ohms. This corresponds to a circuit design with a differential configuration, which is recently becoming popular, even in the high frequency range, for the stable and improved linearity of the wireless circuits, and which is equivalent to supplying RF power through two 50-ohm unbalanced coaxial cables.

The minimum operable frequency at which VSWR decreases to 2 is approximately 4 GHz or higher for Models A and B, and 3 GHz for Model C. Compared with Model B, Model C shows an improvement of approximately 3.5 in VSWR at 3 GHz. Figure 8 shows the effective radiation efficiencies, including the effect of reflection loss (The effective radiation efficiency=radiation efficiency/M where M is the reflection loss). The improvement in the effective radiation efficiency for Model C at 3 GHz is caused by the lower reflection loss at the frequency.

3. Current distributions

Current distributions of the antenna as a standalone unit, and current distributions when fitted on the finger, are shown in Figs. 10 and 11 respectively. With the antenna as a standalone unit, current flows strongly in the ring-shaped element. Particularly in the ring-shaped element, nodes occur at which the current distribution is frequency-selectable, which is thought to correspond to a variation in impedance characteristics with frequency.

On the other hand, when the antenna is fitted on the finger, it is apparent that the proportion of current flowing in the ring-shaped element is reduced. Furthermore, in comparison with the antenna as a standalone unit, it is apparent that more current flows in an elliptical element (compared with the current flows along the ring-shaped element) at all frequencies (including that of 3GHz). A ring-shaped element may act as an earthing plate or simple radial earth. By fitting it on the finger the upper elliptical element (the radiating element) operates effectively, thus stabilizing the impedance characteristics. From another perspective, the presence of the finger may result in the occurrence of a suitable dumping factor, giving rise to an improvement in the impedance characteristics over a wide range (including the lower frequencies).

4. Conclusions

This paper describes the basic characteristics of three types of radiating element for UWB antennas placed in the vicinity of a human finger for a wearable UWB antenna fitted on the finger. A ring-type lower element was proposed to improve the impedance characteristics and radiation efficiencies of a further two types of radiating element. Finally, the proposed ring-type radiating element was evaluated in terms of current distribution, the mechanism by which the desirable characteristics for a wearable antenna when fitted on the finger are derived, and its effectiveness was confirmed.

Acknowledgments

Part of this study was conducted under the auspices of a Grant-in-Aid for Scientific Research (basic research (B) 1830023) of the Japan Society for the Promotion of Science. Also, this study received assistance from ‘Combined Large-scale Sensor System for Disaster Prevention and Safety and the Establishment of Robust Network’ of High-tech Research Center Improvement Project for the Advancement of Academic Research in Private University by the Ministry of Education, Culture, Sports, Science and Technology.

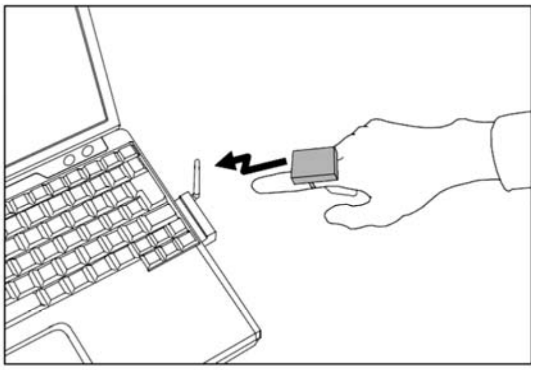

Figure 1: Image (mode of use) of the wearable device.

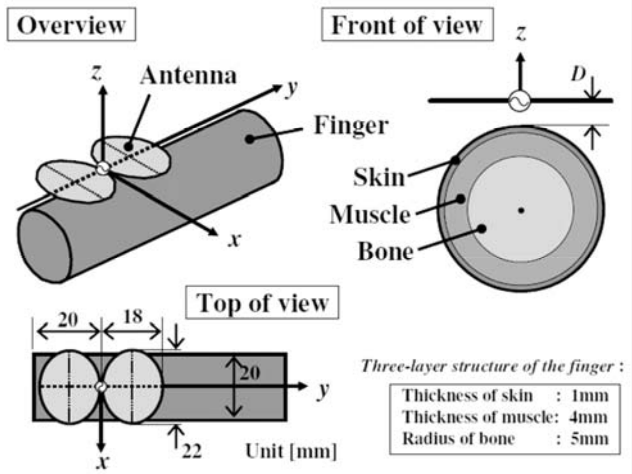

Figure 2: Analytical model.

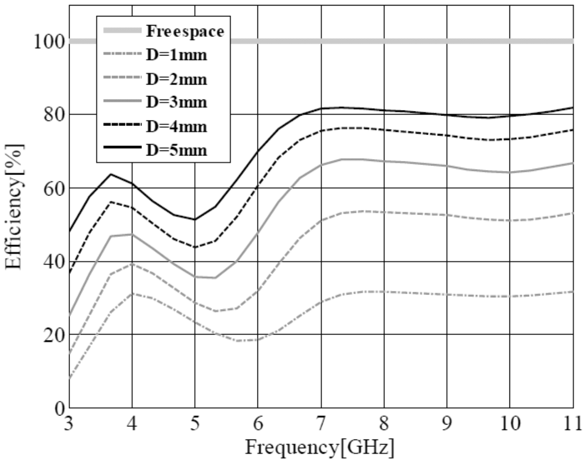

Figure 3: Radiation efficiency.

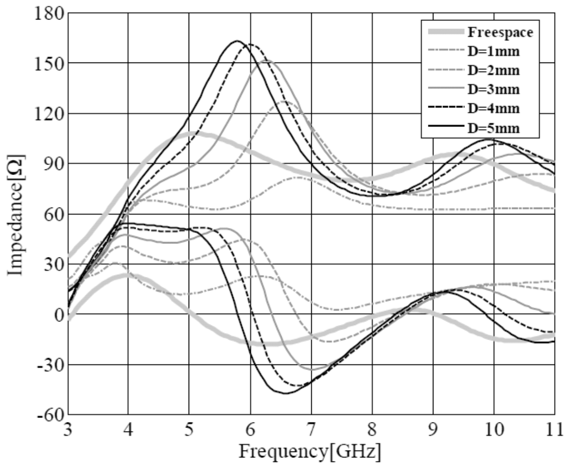

Figure 4: Input impedance.

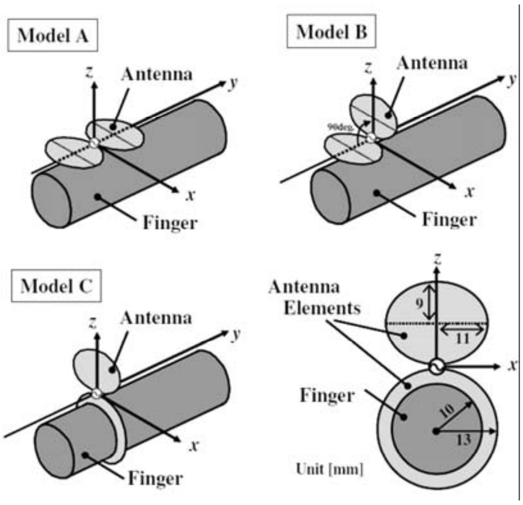

Figure 5: Analytical models.

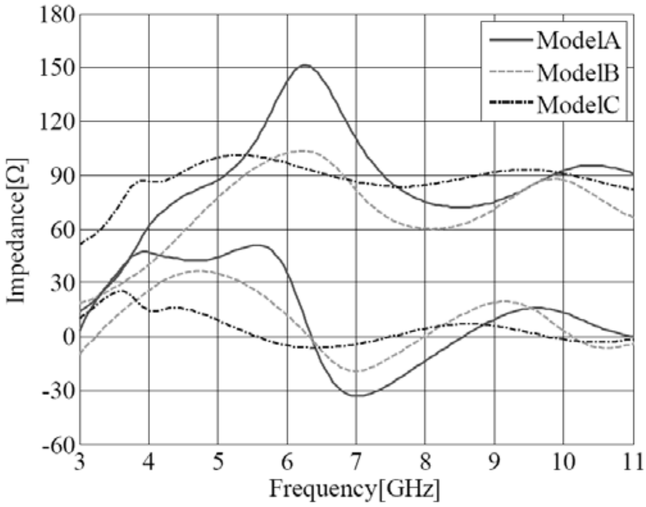

Figure 6: Input impedance.

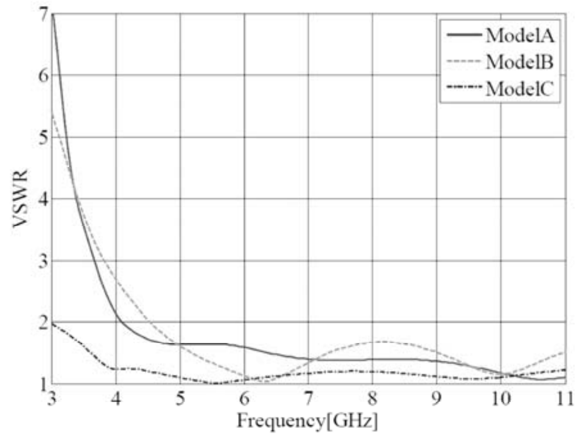

Figure 7: VSWR to a 100-ohm line.

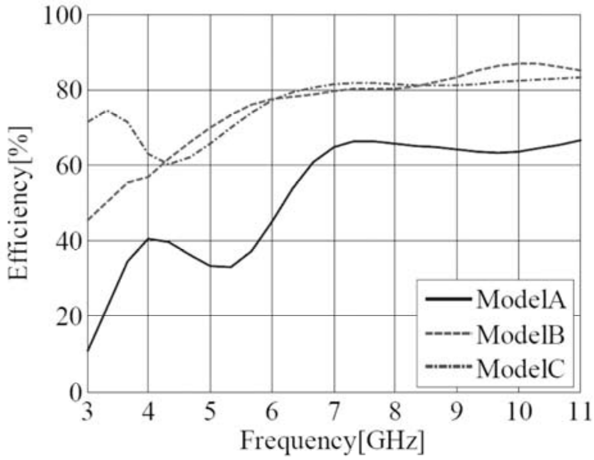

Figure 8: Effective radiation efficiency.

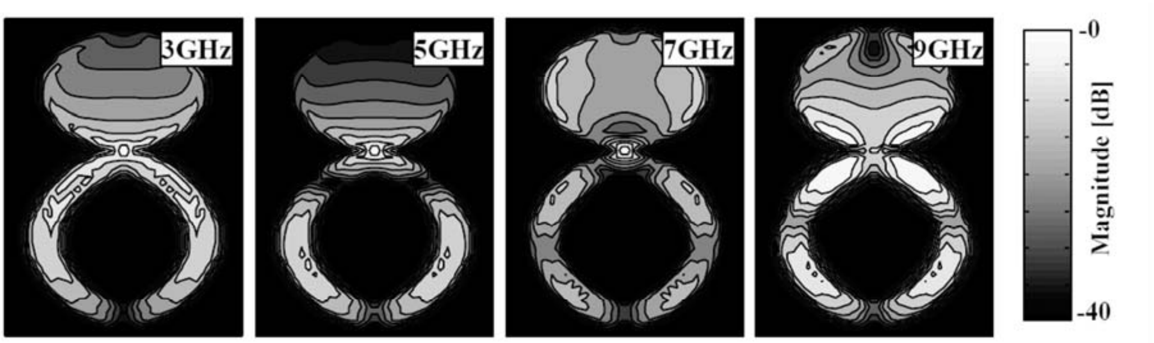

Figure 9: Relative current distributions (Model C) without finger as a standalone unit.

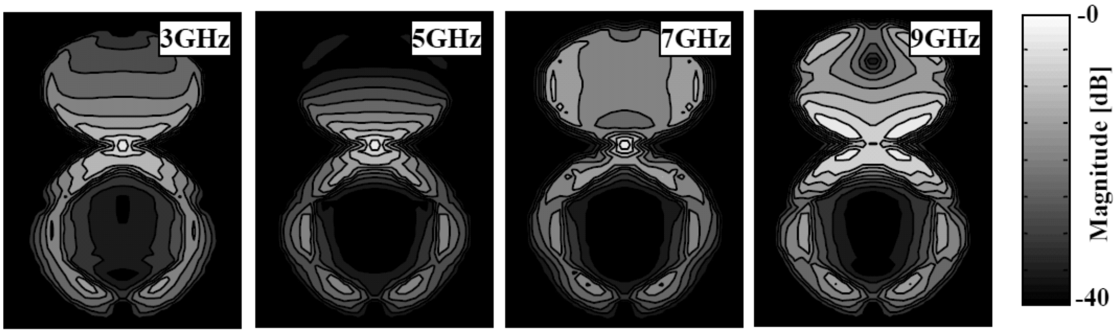

Figure 10: Relative current distributions (Model C) with finger as shown in Fig. 5.

References

[1] L.-C. Kuo, W.-T. Chen, and H.-R Chuang, “Numerical Computation of Human Body Effects on Radiation Characteristics of Loop Antennas for Watch-Type Wrist Radiophone Applications,” Proc. APMC 2001, Volume 3, pp. 1307-1310, Dec. 2001.

[2] T. B. Welch, R. L. Musselman, B. A. Emessiene, P. D. Choudhury, D. N. Cassadine, and S. M. Yano, “The effects of the human body on UWB signal propagation in an indoor environment,” IEEE Journal on Selected Areas in Communications, vol. 20, No. 9, pp. 1778-1782, Dec. 2002.

[3] M. Klemm, I. Z. Kovcs, G. F. Pedersen, and G. Troster, „Novel small-size directional antenna for UWB WBAN/WPAN applications, „ IEEE Trans. Antennas Propag., vol. 53, pp. 3884-3896, Dec. 2005.