Wristwatch-Type UWB Antenna for Wireless Body Area Network

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1. Introduction

After the ultra wide band (UWB) is authorized by Federal Communication Committee (FCC) in 2002, many UWB antennas have been proposed [1]. Since UWB communications have a large-capacity data transmission and low radiation power, this communication system has been expected to expand to popular wireless techniques in the near future. Meanwhile, the wireless body area network (WBAN) has been researched recently [2], [3]. Because the WBAN with UWB technique is applicable to various fields such as entertainment, medical areas etc, the development of UWB antenna for WBAN has occupied the attention and has been practically proposed [4] - [7].

In this paper, a wristwatch-type UWB antenna placed on an arm is proposed. The proposed antenna targets to operate in the band of 7.25 to 10.25 GHz [8]. This band is approved as upper band of UWB in Japan, and it is not necessary to consider the detect and avoid (DAA) mechanism. This antenna is designed to propagate towards the tip of the arm for the communication with an external device located in its direction. Additionally, co-polarization of wearable antenna is vertical, because the vertical electric component to the arm is advanced to propagate along the surface of the arm [9]. The planar monopole antenna, which radiates a vertical electric field, is suitable as a wearable antenna. However, the structure is large to be applied in practice. Wearable devices are required to be a miniature. Since the proposed antenna is small enough, it can be embedded in the wristwatch. In this paper, the characteristics of the proposed antenna are investigated when the antenna is placed on the arm. The voltage standing wave ratio (VSWR), the electric field distribution in near-field, and the radiation pattern in far-field of the antenna are calculated and measured.

2. Models for Calculations and Measurements

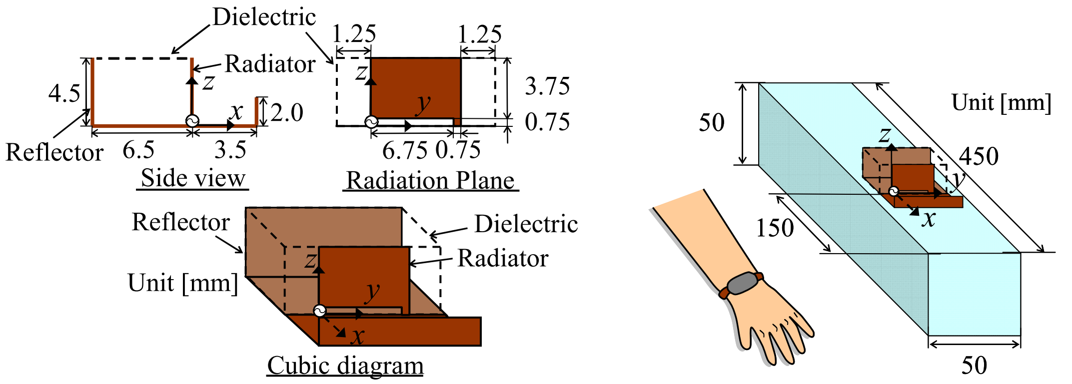
Figure 1 (a) shows the structure of proposed antenna. A half of broadband planar antenna [10] is arranged on the ground plane, and a reflector on $-x$ direction is placed to propagate to $+x$ direction at an advantage. Since electric current on the ground plane decreases the radiation efficiency, a edge of ground plane of the $+x$ direction is bended up. Additionally, a dielectric material ($\varepsilon_r = 4.1$) is put in the space between the radiator and the reflector to maintain the physical robustness of antenna. The overall volume is 10.0 × 10.0 × 4.5 mm^3 and is small enough as a wearable UWB antenna.

Figure 1 (b) illustrates the antenna mounted on the arm assumed as 2/3-muscle equivalent phantom with 450 × 50 × 50 mm^3 of rectangular parallelepiped. Since the human tissue is a dispersive material, the complex dielectric constant ε^* of the arm is expressed by Debye's dispersion equation as

$$\varepsilon^* = \varepsilon_0(\varepsilon' - j\varepsilon'') = \varepsilon_0\left(\varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau}\right)$$

where ω is the angular frequency, ε_s is the static permittivity, ε_∞ is the optical permittivity, and τ is the relaxation time. In this paper, ε_s, ε_∞, and τ are set as 37.1, 7.2, and 11.5 × 10^{-12} s, respectively. Figure 2 shows electrical constants of phantom which is manufactured by us, calculated approximately by the Debye's dispersion equation, and target values from the reference [11]. Figure

2 shows the measured and calculated values, these are compared with the target. The error is within 10.8 %, and has little influence on antenna measurement such as input impedance and radiation pattern [12]. The antenna is placed where a feeding point of antenna is 150 mm from the tip of the arm as shown in Fig. 1 (b). Since the antenna is loaded into a case in practice, the distance between the bottom of antenna and the surface of arm is set to 1 mm. The characteristics of antenna with the arm are calculated the finite-difference time-domain (FDTD) method (XFDTD ver.6.2) [13].



(a) Structure of proposed antenna. (b) Position of the antenna on the arm.

Figure 1: Models for calculations and measurements.

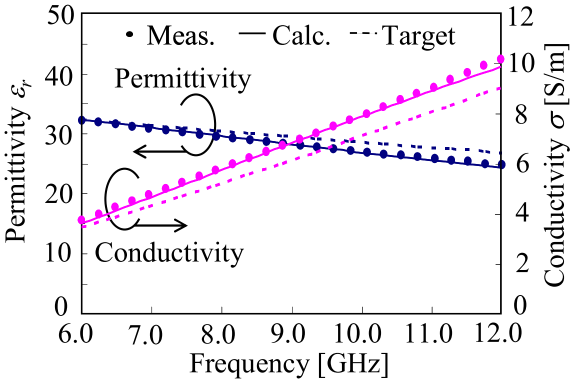


Figure 2: Electrical constants of the arm.

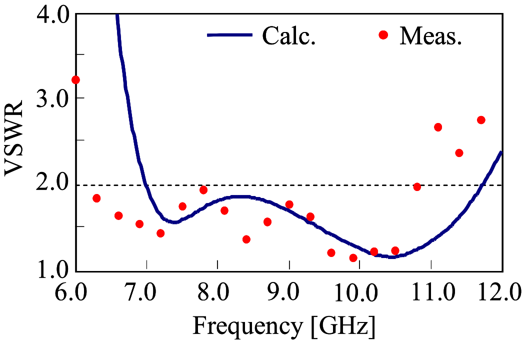


Figure 3: VSWR of the antenna.

3. Characteristics of Antenna

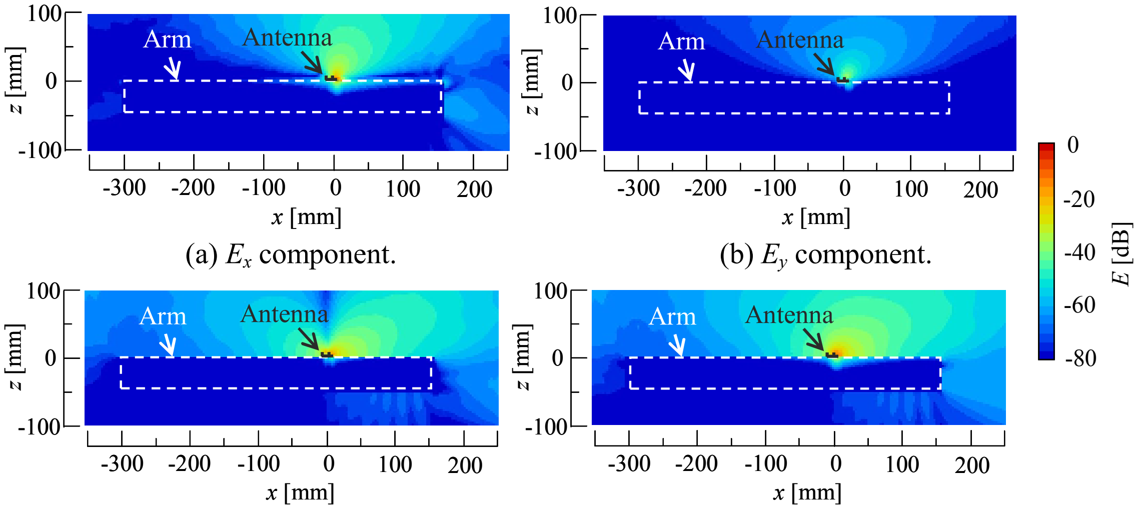
3.1 VSWR

Figure 3 presents VSWR of the antenna, when the antenna is placed on the arm. The calculated and the measured bandwidths with VSWR lower than 2.0 are 7.00 - 11.69 GHz and 6.27 - 10.80 GHz, respectively. Although the resonant frequency by numerical calculation is higher than the measurement, both results satisfy with the required bandwidth. The difference between the calculation and the measurement is caused by an error in the manufacture of the antenna.

3.2 Electric Field Distributions

Figure 4 shows the calculated electric field distributions of E_x, E_y, E_z, and root-sum-square of three components at 8.75 GHz, which is central frequency in the target band. Each electric field is normalized with the maximum value of root-sum-square. Feeding point is coordinate origin. The observation plane is the *zx*-plane (y= 3.75 mm) with the center of the arm. The area of more than -40 dB is broad toward tip of the arm (+*x* direction) compared with the back direction (-*x* direction). It is confirmed that the electrical field intensity at the tip of the arm is higher than at the back of the arm. Therefore, the antenna is adequate the communication toward the tip of the arm. Moreover, the intensity of E_z component is stronger than them of E_x and E_y components on the surface of the arm. Therefore, it is certified that the dominant component of the antenna is the vertical component to surface of the arm.

Figuare 5 is the electric field distributions of root-sum-square of three component at 7.25 and 10.25 GHz, which are the minimum and maximum frequencies in the target band, respectively. The area, that electric field intensity is more than -40 dB, is broad toward tip of the arm (+*x* direction) compared the back direction (-*x* direction) as well as Fig. 4. Therefore, it is achieved that the proposed antenna is communicable toward the tip of the arm at all of the taget band. However, the electric field of back direction at 7.25 GHz is relatively stronger than other frequencies, because the electromagnetic wave is easy to diffract to the back of the reflector in a low frequency. From the results of Figs. 4 (d), 5 (a) and (b), when a frequency rises, propagation of the electric field inner arm decreases, because the conductivity of the arm becomes higher.



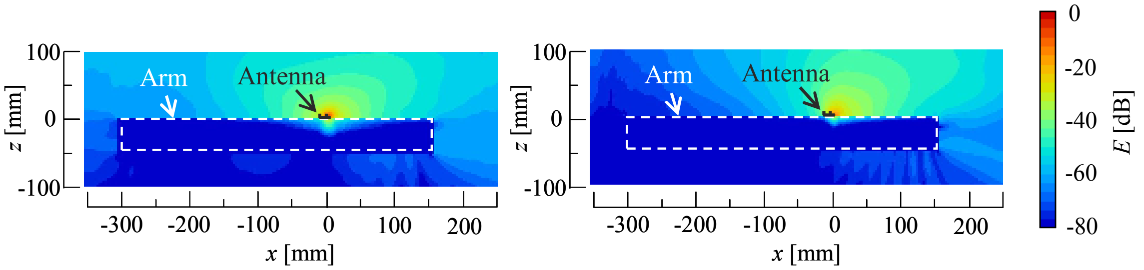
(a) E_x component.

(b) E_y component.

(c) E_z component.

(d) root-sum-square.

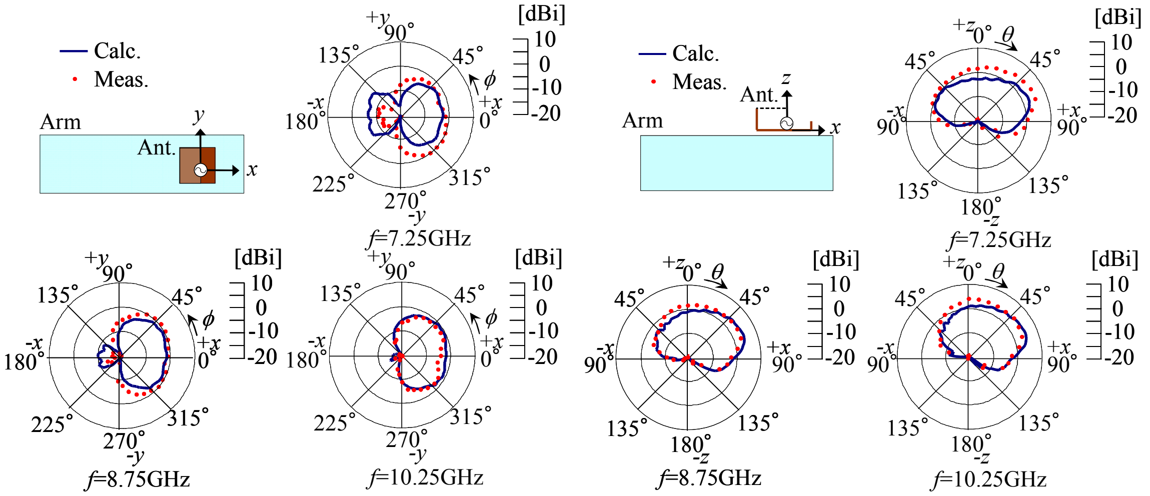
Figure 4: Electric field distributions at 8.75 GHz.



(a) At 7.25 GHz.

(b) At 10.25 GHz.

Figure 5: Electric field distributions (root-sum-square).



(a) *xy* plane.

(b) *zx* plane.

Figure 6: Radiation patterns.

3.3 Radiation Patterns

Figure 6 shows calculated and measured radiation patterns (E_θ) in *xy*- and *zx*-planes at 7.25, 8.75, and 10.25 GHz, when the antenna is mounted on the arm. The measured results agree almost with the calculated ones. The front-to-back (FB) ratios are approximately 5 dB at 7.25 GHz, 10 dB at 8.75 and 10.25 GHz. The FB results mean that main lobes are inclined toward the tip the arm same as the near-field distributions shown in previous section. The radiation toward the back direction at 7.25 GHz is stronger than at other frequencies for same reason of previous section.

From the results in near-field distribution and far-field radiation pattern, it is confirmed that the proposed antenna satisfies the requirements for the communication with an external devices situated in the tip of the arm.

4. Conclusion

In this paper, we proposed a wristwatch-type broadband antenna which is small enough to be wearable, and investigated the characteristics of its. From the frequency characteristic, it is confirmed that VSWR is less than 2.0 from 7.25 to 10.25 GHz, which is approved UWB system in Japan. From electrical distributions in near-field, it is confirmed that co-polarization of the antenna is vertical component. The antenna radiates stronger to the tip of the arm than to the back direction by near- and far-field results. Consequently, the antenna is useful to a wearable device of wristwatch-type in practice.

In the next step, the proposed antenna will be applied to investigate the communication links among some wearable devices on the human body.

References

[1] Z. N. Chen, “UWB Antennas: Design and Application,” ICICS 2007, Dec. 2007.

[2] T. G. Zimmerman, “Personal Area Networks (PAN): Near-Field intra-body communication,” IBM Systems J., vol.35 no. 3&4, pp. 609-617, 1996.

[3] Y. Hao and P. S. Hall, “On-Body Antennas and Propagation: Recent Development,” *IEICE Trans. Commun.*, vol.E91-B, no.6, pp.1682-1688, June 2008.

[4] 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.

[5] M. Klemm, G. Troester, “Textile UWB Antennas for Wireless Body Area Networks,” *IEEE Trans. Antennas Propag.*, vol.54, no.11, pp.3192-3197, Nov. 2006.

[6] Z. N. Chen, A. Cai, T. S. P. See, X. Qing, and M. Y. W.Chia, “Small Planar UWB Antennas in Proximity of the Human Head,” *IEEE Trans. Microw. Theory Tech.*, Vol.54, no.4, pp1647-1652, Dec. 2006.

[7] J. R. Verbiest and G. A. E. Vandenbosch, “A Novel Small-Size Printed Tapered Monopole Antenna for UWB WBAN,” *IEEE Antennas and Wireless Propag. Lett.*, vol.5, pp. 377-379, Dec. 2006.

[8] The Wireless USB Promoter Group [Online]. Available: http://www.usb.org/developers/wusb/

[9] N. Haga, K. Saito, M. Takahashi, and K. Ito, “A cavity-backed slot antenna for on-body BAN devices,” *Proc. of the International Workshop on Antenna Technology 2008*, pp.510-513, Chiba, Japan, Mar. 2008.

[10] Y. Okano, “A Simple Shape Broadband Planar Antenna Adaptable to RFID-Tag,” *IEEE Trans. Antennas Propag.*, vol.54, pp. 1885-1888, June 2006.

[11] IFAC Dielectric Property of Body Tissue [Online]. Available: http://niremf.ifac.cnr.it/tissprop/

[12] T. Takimoto, K. Saito, M. Takahashi, S. Uebayashi, and K. Ito, Evaluation on biological tissue equivalent agar-based solid phantoms up to 10 GHz aiming at measurement of characteristics of antenna for UWB communications,” *2005 International Symposium on Antennas and Propagation*, vol.2, pp.483-486, Seoul, Korea, Aug. 2005.

[13] Remcom Inc. [Online]. Available: http://www.remcom.com