A Reduced-Size Wide Slot Antenna for Enhancing Along-Body Radio Propagation in UWB On-Body Communications

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Abstract—In this paper, a 6–10-GHz ultrawideband (UWB) directional reduced-size wide slot antenna (RWSA) for on-body wireless communications is proposed and investigated. The RWSA is designed to be narrow in width and can be mounted on the side of a wireless device. When a side-mounted RWSA is worn on a body, the antenna boresight is naturally directed along the body surface, and most of the energy can be efficiently transmitted by direct or diffracted waves. Consequently, the on-body channel performance can be effectively improved. After a series of on-body channel measurements, the results show that, with the side-mounted RWSAs, the path loss is significantly improved (greater than 20 dB) compared with the results of previous studies, and the sensitivity of the channel to the human body and environment is effectively lessened. An approach to estimate the variation range of path loss in real environments is also proposed at the end of this paper. Index Terms—Body area network (BAN), channel, path loss,communication. ultrawideband (UWB) antenna, wireless

I. INTRODUCTION

USING wireless devices around the body for medical and nonmedical uses are promising new applications. The large diversity and potential of these applications have made wireless body area network (BAN) an exciting research topic in wireless communications. To satisfy the technical requirements, the IEEE 802.15 Task Group (TG) 6 was formed for BAN in 2007. The TG 6 is devoted to developing a communication standard for low-power devices and applicable to operations on, in, or around the human body. References [1]–[6] report notable achievements of the TG 6. Several frequency bands are proposed for different service scenarios in [1]. According to [1], the scope of this paper is categorized as scenarios S4 and S5, which stand for line-of-sight (LOS) and non-line-of-sight (NLOS) on-body (body surface to body surface) communications, respectively. The corresponding channel model is CM3 with ultrawideband (UWB) frequency band.

In on-body communications, the presence of the body strongly influences various antenna characteristics, primarily the impedance matching and radiation pattern. Particularly, the antenna radiation pattern determines the dominant propagation mode and path, consequently strongly influencing the channel performance (such as path loss and sensitivity to the environment).

Therefore, the antenna used in on-body communications is crucial, and designing an efficient on-body antenna is challenging. The primary purpose of this study is to develop a UWB antenna, which is less sensitive to the human body, can effectively minimize path loss and influences from the environment, and can be easily integrated into wireless devices. Finally, it is expected to improve the on-body channel performance with the developed antennas.

Several types of UWB antennas have been proposed for on-body research in previous studies. In [7], textile antennas operating over the entire UWB were reported. The antennas can be directly integrated into clothing and have excellent transient characteristics. Monopole-like antennas that exhibit omnidirectional patterns are appropriate for use in on-body wireless links when the antennas are positioned perpendicularly to the body surface. However, this type of antenna is too large for practical implementation. In [8], a low-profile inverted truncated annular conical dielectric resonator antenna (DRA) with wide bandwidth and stable monopole-like patterns was proposed. The low-profile feature enables the DRA to be potentially useful in on-body applications. Goto and Iwasaki [9] proposed a finger-ring UWB monopole antenna; this novel, wearable antenna may increase the diversity of wireless applications. Loop antennas can also be applied to BANs. Yazdandoost and Hamaguchi [10] proposed a small loop antenna printed on a silicon substrate; the antenna is small enough to be fit into medical BAN devices. The effects of human body tissues on the loop antenna were also analyzed.

If the feasibility of integrating antennas into modern commercial wireless devices is considered, printed planar antennas are preferred because of their low form factor and ease of fabrication. Several UWB planar antennas have been used in on-body studies [11]–[17]; however, because of their large sizes, the antennas were worn parallel, rather than vertically, to the body during measurements. In this mounting configuration, the body blocks one side of the radiation of any omnidirectional planar antenna. The resultant radiation pattern is directional and the direction of the main beam is oriented outward from the body [16]. For a directional planar antenna, the body may not have strong influence to its patterns [17], but the boresight is still aimed outward from the body. Therefore, when any antenna used in [11]–[17] is employed in on-body communications, most energy radiates away from the body. This results in a high path loss because the direct EM energy transmission along the body surface (shortest distance between the antennas) is relatively small. Furthermore, channel performance could be sensitive to the environment because signal transmissions highly rely on the reflections of nearby scatterers. If any of these antennas is mounted on the front of a device, the device would alter the antenna characteristics, similar to the way the body does.

Chahat et al. [18] proposed a compact planar UWB monopole antenna. This small antenna can be placed perpendicularly to the body, which can effectively reduce the influence that the body exerts on the antenna. Consequently, satisfactory on-body propagations were obtained using this antenna. However, if this compact antenna is integrated into a wireless device, its characteristics would be strongly influenced by the device because there is no shield between the antenna and the device. Compared with the previous studies, one distinct motivation in this paper is that the goal is to develop an antenna that is suitable for integration in commercial products. Directional planar antennas are preferred in this research because they exhibit lower susceptibility to influences caused by their backside objects, compared with omnidirectional planar antennas. Then, the most important issue becomes that of designing a directional planar antenna which is appropriate in size and works efficiently.

In this paper, a directional reduced-size wide slot antenna (RWSA) is proposed; its narrow width allowed it to be mounted on the side of a wireless device. When a side-mounted RWSA is worn on a human body, the antenna is positioned perpendicularly to the body, and the antenna boresight is naturally directed along the body surface, allowing more electromagnetic (EM) energy to be transmitted along a direct path. Consequently, using side-mounted RWSAs can achieve highly efficient on-body communications. Furthermore, a side-mounted RWSA may not increase the device's thickness, and there is an extra advantage. Most modern wireless devices generally have a large front display. A side-mounted antenna is favorable because it requires less space on the device front. A distinct feature of the proposed RWSA is that a reflector and a folded ground are introduced to enhance the impedance bandwidth. A wide impedance bandwidth (S11<- 10 dB) over the frequency range of 6–10 GHz is achieved. After a series of on-body channel measurements, the results show that, with the fabricated RWSAs, the channel performance can be substantially improved.

In this paper, Section II presents an introduction of the RWSA design. Section III presents the measured characteristics of a fabricated RWSA. Finally, Section IV presents a description of on-body channel measurements and their results. In this section, a measurement approach is proposed that can estimate the variation range of channel path loss in real environments. This approach provides an effective measure for comparing the performances of antennas.

II. ANTENNA DESIGN

The idea of side-mounted antenna is promising. However, designing a directional planar antenna with a narrow width and simultaneously achieving a predetermined goal of impedance

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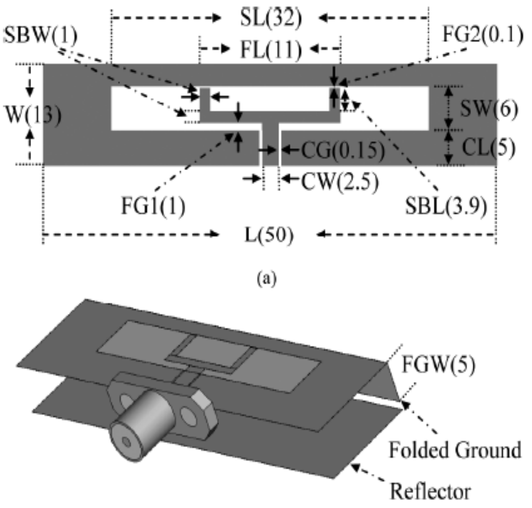


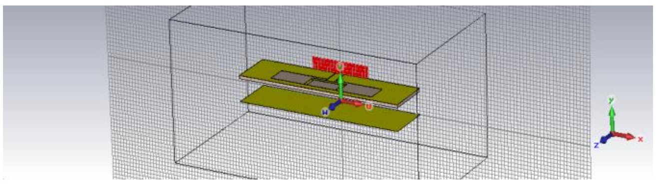
Fig. 1. Structure of the RWSA and its major dimensions (unit in millimeter):
(a) the antenna element; and (b) the entire configuration, comprising the reflector
and the extended folded ground (detailed parameter descriptions are listed in
Table I).

bandwidth (6–10 GHz) is challenging. Among wideband planar antennas, the concept of wide slot antenna (WSA) was chosen because of the following reasons. First, the impedance bandwidth can be enhanced with a fork-like tuning stub [19], and achieving UWB bandwidth has been reported [20], [21]. Second, the radiation pattern can be modified from omnidirectional to directional by introducing a reflector [22]. Third, the antenna exhibits stable gain patterns and good time-domain responses [23].

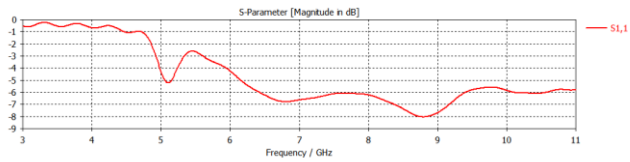
Nevertheless, conventional WSAs are too large to be side-mounted. If the antenna width is shortened directly, the impedance matching will be severely deteriorated; solving this problem is the primary challenge in the antenna design. The structure of the proposed RWSA is shown in Fig. 1. The antenna is printed on a 0.813-mm-thick Rogers RO4003 substrate with a dielectric constant of 3.38. The wide slot is fed by a coplanar waveguide (CPW) with a fork-like tuning stub. A CPW feeding structure was chosen because of easier fabrication. As mentioned above, shortening the antenna width directly will cause the loss of wide impedance bandwidth. For an RWSA, a 6–10-GHz bandwidth is not obtainable by simply tuning the dimensional parameters shown in Fig. 1(a). The key in this design is introducing a reflector and an extended folded ground into the antenna, as shown in Fig. 1(b). The original function of the reflector is to block the backward radiation and, therefore, reduce the interaction between the antenna and its backside objects (e.g., the user’s body or electronic devices). However, the input impedance of a WSA is strongly influenced by introducing a reflector, especially when the spacing between the antenna element (fork-like tuning stub and ground) and the re- flector is small (such as <10 mm). Typically, adding a reflector to a matched WSA degrades its impedance matching [22].

Folded Ground-1

Design



s-parameters



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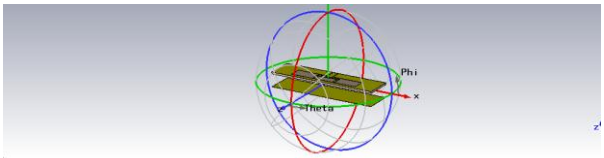
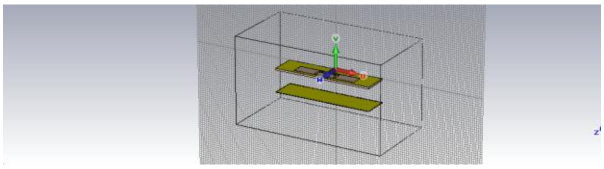
Radiation Patern

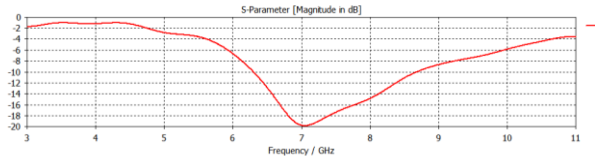


Folded Ground – 2

Design



S-Parameters



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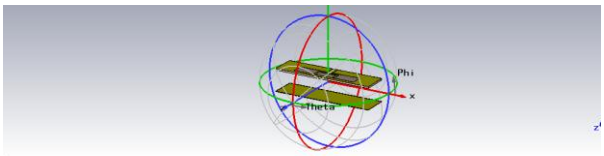


Fig. 2. Impedance bandwidth enhanced by introducing a reflector and a folded ground.

However, in this study, in addition to blocking the backward radiation, the reflector is also used to transform the input impedance of a poorly matched shortened WSA. With appropriate design, the originally poor impedance matching could be significantly improved. Moreover, a larger ground could also enhance the impedance bandwidth. To avoid enlarging the antenna size, a folded ground is introduced to the antenna. Simulated results (with CST Microwave Studio) demonstrate how the reflector and the folded ground improve the impedance bandwidth, as shown in Fig. 2. Without the reflector and the folded ground, the reflection performance is poor (No_Rft_No_FG). After placing a reflector at a distance of 7 mm, the impedance bandwidth of the antenna is significantly improved (7 mm_Rft_No_FG). If a folded ground is added, the impedance bandwidth is further enhanced (7 mm_Rft_with_FG). The bandwidth improvement is due to two resonances introduced by the reflector and the folded ground. The antenna element is printed on the side facing the reflector so that the substrate can prevent the antenna element from being touched by objects, such as fingers. In Fig. 1(b), the substrate is set to be transparent to visualize the antenna element. In addition to introducing the reflector and the folded ground, more elaborate design was required to achieve a wide impedance bandwidth. During the design process, the antenna length (L) was fixed, and the antenna width (W) and the slot width (SW) were gradually reduced. After the predetermined 6–10-GHz impedance bandwidth was achieved at a selected width (W or SW), the width was then reduced by 1 mm, and the next design process was carried on. This procedure explains why a predetermined impedance bandwidth is required. All of the dimensional parameters shown in Table I have influences on the impedance matching. Among the parameters, the slot length (SL), the fork-like stub length (FL), the spacing (SP), the folded ground width (FGW), and the stub branch section length (SBL) are critical; thus, these parameters are discussed in the following paragraphs. The remaining parameters were determined after several preliminary simulations and kept invariant throughout the design process.

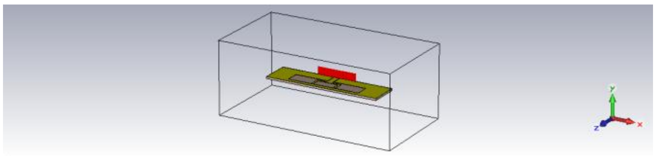
In the following analyses, the dimensional parameters were properly selected to obtain two resonance frequencies. Subsequently, the value of one selected parameter was varied to investigate its influence on the reflection coefficients (S11 in decibels). Fig. 3(a) and (b) shows the effects of varying the SL and FL, respectively. It is observed that the upper resonance frequency of the antenna shifts higher as the SL or FL is reduced. The SL and FL show similar effects on the reflection coefficients.

TABLE I
DIMENSIONAL PARAMETERS OF THE RWSA

Antenna Dimensional Parameters	Initial Value (mm)	Final Value (mm)
Antenna length (L)	50	50
Antenna width (W)	50	13
Antenna thickness (T)	9	7
Substrate thickness (ST)	0.813	0.813
Slot length (SL)	32	32
Slot width (SW)	21	6
Reflector length (equal to L)	50	50
Reflector width (equal to W)	50	13
Feeding CPW length (CL)	15	5
CPW center conductor width (CW)	2.5	2.5
CPW slot width (CG)	0.15	0.15
Gap width, between horizontal section and ground (FG1)	1	1
Gap width, between branch sections and ground (FG2)	10	0.1
Fork-like stub horizontal section length (FL)	16	11
Fork-like stub branch section length (SBL)	10	3.9
Fork-like stub line width (SBW)	2	1
Folded ground length (equal to L)	none	50
Folded ground width (FGW)	none	5
Spacing between antenna element and reflector (SP)	8	6

These results are reasonable because the radiation of the antenna is mainly controlled by the fork-like stub and the slot. As these elements are smaller, it is predictable that the resonance frequency will be higher. The lower resonance frequency is not sensitive to the SL or FL. Therefore, shortening the SL or FL might cause the two resonance frequencies to be separated excessively, and that could result in higher S11 at the frequencies between the two resonance frequencies, for example, frequencies near 7.5 GHz in Fig. 3(a). In addition, operating frequencies higher than 10.6 GHz are not desired because using these frequencies is not allowed without a license. Therefore, the SL and FL cannot be too short. Fig. 3(c) shows the effect of varying the SP. It is found that reducing the SP also shifts the upper resonance frequency higher. Smaller SP is preferred because the thickness of the antenna can be reduced. However, when the reflector is moved closer to the antenna element, the impedance bandwidth becomes narrower. This might be because the increased capacitance leads to more energy stored in the antenna, which increases the quality factor Q of the antenna. By contrast, increasing the SP reduces the effect of the reflector and the impedance matching becomes poorer, as shown in Fig. 3(c) (SP = 14 mm).

BasicDesign



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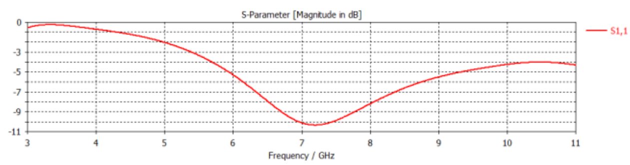
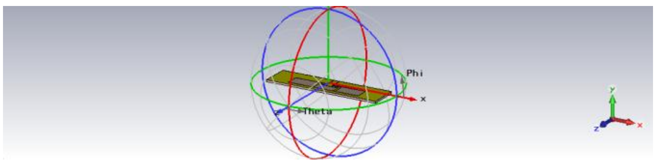
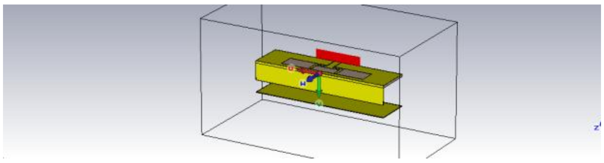


Radiation Patern



Folded Ground with Reflector

Antenna Design



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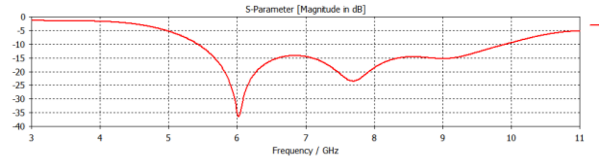

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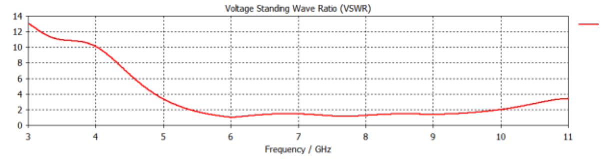
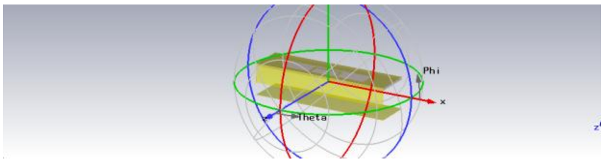
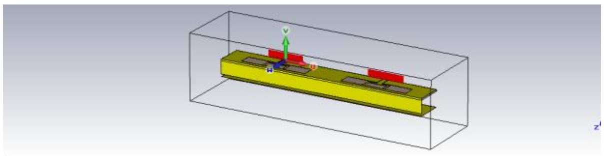


Radiation Parameter

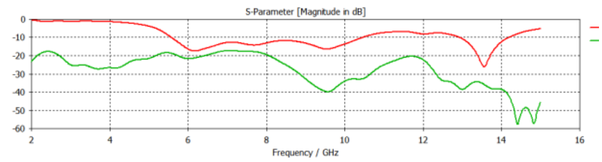


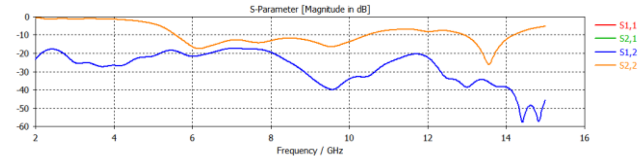
Array Antenna – 2

Antenna Design



S-Parameters





VSWR

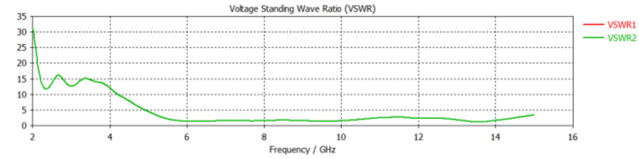


Fig. 3. Effects of selected dimensional parameters on the reflection coefficient or the input impedance.

Fig. 3(e) shows the effect of varying the SBL. It is obvious that the impedance bandwidth is gradually enhanced as the SBL increases. However, the SBL is limited by the slot width because the branch sections must not contact the ground. The character and the function of a branch section are similar to those of a shunt open stub in a microwave circuit. It could provide reactance for impedance matching. For an open stub, the first maximum reactance occurs when the length of the stub is equal to 1/4 wavelength (λ) of the operating frequency, and the reactance gradually reduces as the stub length reduces. If an antenna is initially far from matching, introducing a large reactance might be necessary to transform the input impedance. Fig. 3(f) shows the effect of varying the SBL with a Smith chart (from 4 to 10 GHz). It can be seen that increasing the SBL can effectively transform the input impedance closer to the center (matching) at higher frequencies. For lower frequencies, the SBL is relatively short if compared with the wavelength; thus, the effect of the branch sections is not significant. In this design, the final selected SBL is 3.9 mm, which is near, but shorter than of $^{\lambda}/_{4}$10 GHz. Shortening the antenna width will also shorten the SBL. Consequently, the reactance introduced by the shortened branch sections might be too small to improve the impedance matching effectively. Therefore, the SBL might limit the minimum width of the RWSA. The above analyses were conducted to investigate the influences of some selected parameters by varying only one selected parameter at a time while holding the others fixed. The results provide the basic guidelines in the antenna design. However, modifying one parameter alters the effects of other parameters on the input impedance. Therefore, the design was cumbersome. After extensive simulations and repeated tuning in measurements, the final optimized dimensions were obtained. Table I lists the initial and final dimensions of the RWSA. The final size of the RWSA is 50 (L) X 13 (W) X 7 (T) in millimeters, which is acceptable for general wireless devices. The feasibility of reducing the antenna dimensions is analyzed as follows. The antenna length (L) is not critical and it can be slightly reduced. The antenna thickness (T) is mainly determined by the spacing (SP), and the SP is related to the impedance bandwidth. Reducing the SP also alters the usable frequencies. Minimizing the antenna width (W) to a favorable size and still achieving the predetermined impedance bandwidth is the main effort of the antenna design. The value 13 mm includes the length of the CPW that is used to connect an SMA connector. Thus, the antenna width could be further shortened when an RWSA is integrated in a commercial device because no connector is required for this condition. With modern circuit connection techniques, such as flexible printed circuits, an antenna width shorter than 10 mm could be achievable.

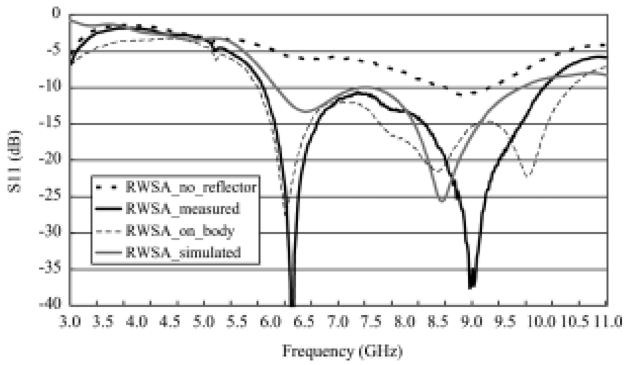


Fig. 4. Measured and simulated reflection coefficients of an RWSA.

V. CONCLUSION

In this paper, a 6–10-GHz directional RWSA is proposed and investigated. The RWSA is narrow in width and can be mounted on the side of a wireless device. Using the side-mounted RWSAs allows more direct energy transmission between antennas. After a series of on-body channel measurements, the results show that, with the side-mounted RWSAs, the path loss is significantly improved, and the channel is less sensitive to the human body and environment.

Path loss is crucial for most wireless communications. Lower path loss permits higher transmission capacity, better communication quality, and lower power consumption. The RWSA and the side-mounted antenna concept are proved effective in reducing the path loss. It is expected that the results of this study can benefit the development of on-body communications.

The RWSA is a directional antenna. One RWSA cannot cover every direction along the body. However, this problem can be solved with modern multiple-input–multiple-output (MIMO) technology. It is easy to mount a second RWSA on a different side of the device. In fact, the RWSA is also designed for on-body MIMO studies. The on-body communications are expected to gain benefits from the MIMO technology using RWSAs.

REFERENCES

[1] Channel Model for Body Area Network (BAN), P802.15–08-0780–11- 0006, IEEE, Sep. 2010, K. Y. Yazdandoost and K. Sayrafian-Pour.

[2] TG6 Technical Requirements Document (TRD), P802.15–08-0644–09- 0006, IEEE, Nov. 2008, B. Zhen, M. Patel, S. Lee, E. Won, and A. Astrin.

[3] IEEE Standard for Local and Metropolitan Area Networks—Part 15.6: Wireless Body Area Networks, IEEE Standard 802.15.6, 2012.

[4] A. Reichman, "Standardization of body area networks," in Proc. IEEE Int. Conf. Microw. Commun. Antennas Electron. Syst., 2009, DOI: 10.1109/COMCAS.2009.5385994.

[5] C. Lee, J. Kim, H. S. Lee, and J. Kim, "Physical layer designs for WBAN systems in IEEE 802.15.6 proposals," in Proc. 9th Int. Symp. Commun. Inf. Technol., 2009, pp. 841–844.

[6] K. S. Kwak, S. Ullah, and N. Ullah, "An overview of IEEE 802.15.6 standard," in Proc. 3rd Int. Symp. Appl. Sci. Biomed. Commun. Technol., Nov. 2010, DOI: 10.1109/ISABEL.2010.5702867.

[7] M. Klemm and G. Troester, "Textile UWB antennas for wireless body area networks," IEEE Trans. Antennas Propag., vol. 54, no. 11, pt. 1, pp. 3192–3197, Nov. 2006.

[8] G. Almpanis, C. Fumeaux, J. Fröhlich, and R. Vahldieck, "A truncated conical dielectric resonator antenna for body-area network applications," IEEE Antennas Wireless Propag. Lett., vol. 8, pp. 279–282, 2009.

[9] H. Goto and H. Iwasaki, "A finger-ring UWB monopole antenna for BAN and PAN," in Proc. IEEE Antennas Propag. Soc. Int. Symp., Jul. 2010, DOI: 10.1109/APS.2010.5561689.

[10] K. Y. Yazdandoost and K. Hamaguchi, "Very small UWB antenna for WBAN applications," in Proc. Int. Symp. Med. Inf. Commun. Technol., Mar. 2011, pp. 70–73.

[11] A. Fort, C. Desset, J. Ryckaert, P. D. Doncker, L. V. Biesen, and P. Wambacq, "Characterization of the ultra wideband body area propagation channel," in Proc. Int. Conf. Ultrawideband, Zurich, Switzerland, 2005, DOI: 10.1109/ICU.2005.1569950.

[12] A. Fort, J. Ryckaert, C. Desset, P. D. Doncker, P. Wambacq, and L. V. Biesen, "Ultra-wideband channel model for communication around the human body,"

IEEE J. Sel. Areas Commun., vol. 24, no. 4, pp. 927–933, Apr. 2006.

[13] T. S. P. See, A. Alomainy, Y. Hao, and Z. N. Chen, "On-body characterisation of a compact planar UWB antenna," in Proc. Eur. Conf. Antennas Propag., 2006, DOI: 10.1109/EUCAP.2006.4584863.

[14] A. Alomainy, Y. Hao, C. G. Parini, and P. S. Hall, "Comparison between two different antennas for UWB on-body propagation measurements," IEEE Antennas Wireless Propag. Lett., vol. 4, pp. 31–34, 2005.

[15] A. Alomainy, A. Sani, A. Rahman, J. G. Santas, and Y. Hao, "Transient characteristics of wearable antennas and radio propagation channels for ultrawideband body-centric wireless communications," IEEE Trans. Antennas Propag., vol. 57, no. 4, pt. 1, pp. 875–884, Apr. 2009.

[16] T. Tuovinen, K. Y. Yazdandoost, and J. Iinatti, "Monopole ultra wideband antenna for on-body communication in wireless body area network," in Proc. Antennas Propag. Conf., Loughborough, 2011, DOI: 10.1109/LAPC.2011.6114060.

[17] M. Klemm, I. Z. Kovcs, G. F. Pedersen, and G. Tröster, "Novel smallsize directional antenna for UWB WBAN/WPAN applications," IEEE Trans. Antennas Propag., vol. 53, no. 12, pp. 3884–3896, Dec. 2005.

[18] N. Chahat, M. Zhadobov, R. Sauleau, and K. Ito, "A compact UWB antenna for on-body applications," IEEE Trans. Antennas Propag., vol. 59, no. 4, pp. 1123–1131, Apr. 2011.

[19] J.-Y. Sze and K.-L. Wong, "Bandwidth enhancement of a microstripline-fed printed wide-slot antenna," IEEE Trans. Antennas Propag., vol. 49, no. 7, pp. 1020–1024, Jul. 2001.

[20] X. Qing, M. Y. W. Chia, and X. Wu, "Wide-slot antenna for UWB applications," in Proc. IEEE Antennas Propag. Soc. Int. Symp., 2003, pp. 834–837.

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