# Analysis of Channel Characteristic for Body Channel Communication Transceiver Design

Jaeeun Jang(✉) and Hoi-Jun Yoo

KAIST, Yuseong-Gu, Daejeon 34141, Republic of Korea
jaeeun.jang@kaist.ac.kr

**Abstract.** In this paper, body channel communication and its channel characteristic are investigated through measurement. Previously, the body channel communication has limitation in channel bandwidth due to its fluctuation. To verify orientation, 4 independent systemic factors are under test; (1) the size of the signal electrode attaching on the skin, (2) the size of the ground plane (GND) electrode that is not attaching on the skin, (3) the channel distance between TX and RX through human body, and (4) the length of cable connecting between the transceiver hardware and signal electrode. The size of the electrode and channel communication does not have a high correlation, However, the cable length between electrode and device shows a large variation. The newly proposed results are useful for hardware design and allow larger utilizable channel bandwidth that is promising for future BCC hardware design.

**Keywords:** Analysis · Body area network · Body channel communication · BCC · Channel · High data rate · Measurement · Wide-band

## 1 Introduction

Wireless body area network (WBAN) is considered to be an increasingly important technology in our lives. WBAN is one of the most closely engaged communication solutions in the near-human body. It is dedicated to targeting several of miniaturized sensor nodes, portable, multi-media devices, diagnostics, and patients monitoring applications. Especially, IEEE 802.15.6 standard was proposed in early 2010s to support wireless connectivity among devices in, on, and around the human body. The IEEE 802.15.6 WBAN standard consists of three PHYs: ultra-wide-band (UWB) PHY, narrow-band (NB) PHY, and body channel communication (BCC), that is labeled as human body communication (HBC) [1]. The BCC that uses the human body as a communication medium is considered as an energy-efficient PHY since it adopts high conductivity human body as a communication medium, and its low-frequency band enables low power communication. Compare to UWB and NB, BCC signal attenuation near the human body is significantly lower since signal energy absorption in human body tissue decreases [2]. So to say, BCC is one of the most remarkable PHY for hardware design in terms of energy efficiency.

The BCC hardware design research has continued to satisfy key specification such as low-cost, low-power, quality of service (QoS) scalability and so on. The main target applications of BCC can be classified as Fig. 1. First, applications can be grouped as

L. Mucchi et al. (Eds.): BODYNETS 2019, LNICST 297, pp. 374–383, 2019.
https://doi.org/10.1007/978-3-030-34833-5_28

physiological signal monitoring that includes wearable healthcare, patent status monitoring through sensor network coexistence. In the case of physiological, moderate data rate (<1 Mbps), ultra-low-power operation, and high network scalability are highly desired. The 802.15.6 HBC standard is a good fit for these applications since it emphasizes expandability to build sensor network and moderate, and variable data rate up to 1.3125 Mb/s. Second, multimedia applications typically operated under one-to-one connection, and require dedicated hardware design to support high data rate (>10 Mbps) with high energy efficiency. For these applications, the superior concern is low-power consumption, high data-rate for energy efficiency [3]. From the conceptual proposal of capacitive coupling approach [4], BCC researches firstly focused on sensor network applications [5–7], and move on to the high speed, multimedia applications [8, 9].

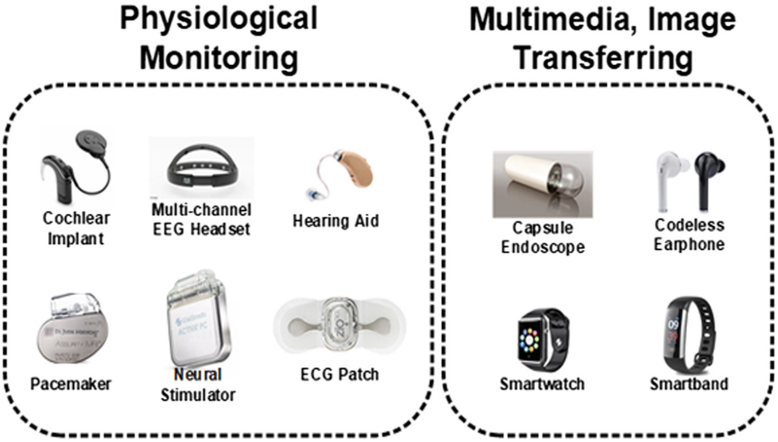


**Fig. 1.** Typical applications of WBAN

For such a hardware design, understand body channel environment is one of the key requirements because; (1) the electrode contact is utilized in BCC instead of antenna interface in RF communication [10]; (2) BCC frequency band located in a boundary of near-field and far-field communication. (3) Communication channel should be characterized before hardware design to set the design parameters and check available channel bandwidth. Especially, verifying both of channel gain or attenuation, and bandwidth should be accompanied. In previous work [11], the body channel bandwidth is verified from 30 MHz to 120 MHz and its bandwidth is verified up to 200 MHz in [9]. However, the detailed measurement process and investigation were not precisely investigated in [9]. For the BCC transceiver design, the electrode, electrode to transceiver interface, and body channel should be considered together since each of the components can affect communication performance.

In this paper, more details of body channel communication verification would be covered. From the review of the measurement setup, measurement to verify the effect of electrodes and cable will be introduced. After that, the paper concludes with a summary.

## 2 Body Channel Measurement

### 2.1 Previous Body Channel Measurements

The earliest human communication model is modeled as a closed loop between the transmitter (TX), receiver (RX) electrodes, and it is realized as capacitive coupling to the human body and earth ground [4]. In particular, the human body itself is modeled on a single node under the assumption of the perfect conductor. This model has the advantage that it is very simple to get intuition and valid for very low frequencies (<few MHz range). However, the model has limitation in that it is very inadequate according to the increase of the distance because the finite impedance of the human body itself is not considered. In order to compensate such a limitation, [11] proposed a distributed RC modeling by assuming the torso of the human body as a T-shape and dividing the human body into multiple distributed unit of RC (resistor-capacitor) networks. The RC distributed model has an advantage that it can be applied to a higher frequency (100 MHz or more). However, in the high frequency band, it has limitation in the low correlation between model and practical measured data. As shown in Fig. 2, there was a fluctuation in the case of the higher frequency range, and this phenomenon was the main reason for limiting the communication bandwidth in BCC. The previous study [12] showed that the frequency and the communication distance becomes a deterministic parameter of the mechanism of the signal propagation. As the frequency increases or the communication distance increases, the near field dominates at the low-frequency range. On the other hands, the far-field dominates in the high frequency region and it is possible to find switching frequency point inside of communication band. As a result, it can be concluded that the hard-to-control far-field term induces certain channel fluctuation in the higher frequency range. So to say, to release far-field occupation in the signal propagation becomes a key consideration in BCC hardware design.

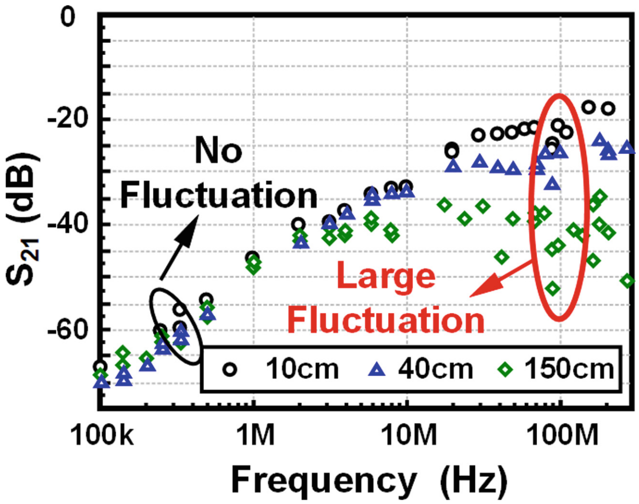


**Fig. 2.** Channel measurement results reported in [11]

The system design factors that can determine the characteristics of BCC channel are analyzed as follows; (1) the size of signal electrode attaching on the skin, (2) the size of the ground plane (GND) electrode that is not attaching on the skin, (3) the channel distance between TX and RX through human body, and (4) the length of cable connecting between the transceiver hardware and signal electrode. Figure 3 shows a generalized diagram of channel model, measurement setup and each of the factors (highlighted in red color). As shown in the figure, the electrode is responsible for the interface between TX, RX, and the human body. The transmitted signal is attenuated through the body channel and measured by a spectrum analyzer or a power detector capable of measuring received signal strength. In the case of measurement using a spectrum analyzer, it is difficult to implement the actual communication environment strictly. Considering impedance matching in the BCC is less feasible due to the variation in contact impedance, and it is difficult to consider the input impedance of the receiver [13]. In addition, the GND plane of spectrum analyzer may affect channel gain. However, it shows low influence in the overall bandwidth of the channel curve, so for the tendency analysis, the spectrum analyzer can be an appropriate solution.

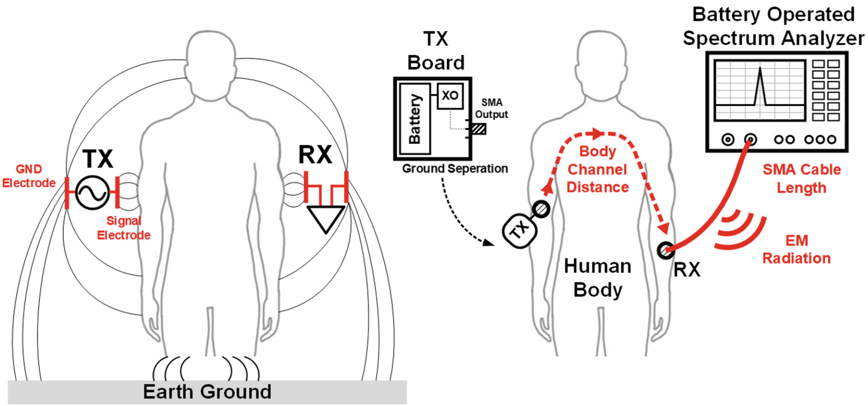
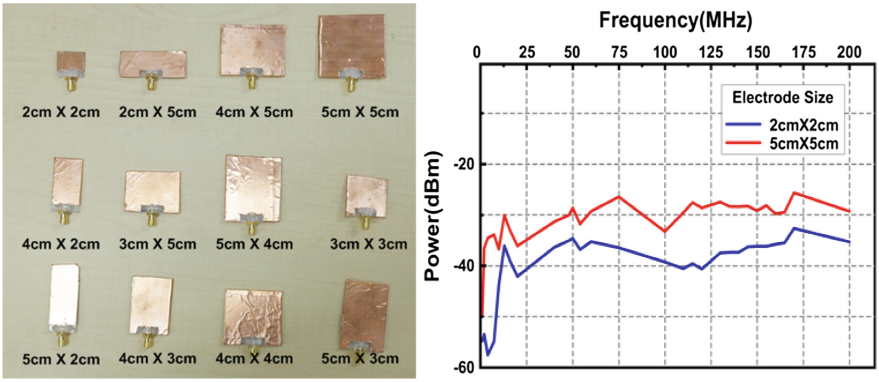


**Fig. 3.** Conceptual capacitive body channel model diagram, and channel measurement setup

The power detector or received signal strength indicator (RSSI) is used to overcome the disadvantages. In this case, the measurement setup becomes more complicated since frequency fundamental tone should be carefully measured. This paper mainly focuses on the measurement of the parameter's effect on channel tendency, so spectrum analyzer is adopted. Based on human body test, the commercial Keysight N9935A is utilized to isolate the GND plane coupling cost-efficiently. The TX is implemented as a customized PCB design, and signal frequency can be set by switching the crystal oscillators. Since the output spectrum power of each frequency may differ, so channel gain is obtained based on frequency-dependent calibration. Based on the measurement setup, 4 factors are measured and investigated.

### 2.2 Channel Effect Measurement with Variable: Signal Electrode Size

Figure 4(a) shows customized test electrodes for the verifying effect of electrode size. The electrode material is based on an attachable copper plate and electrode body is selected square-shaped Polypropylene (PP) plastic to reduce the unwanted effect. Each of electrode plate is connected to SMA connector through soldering. The length of the electrode side is varied from 2 cm to 5 cm. The electrode is connected to the TX board and spectrum analyzer without interconnecting cable.



(a) (b)

**Fig. 4.** (a) Tested electrodes setup (b) measured channel gain results

Figure 4(b) shows channel gain measurement results. Up to 200 MHz frequency is tested and the 2 cm × 2 cm and 5 cm × 5 cm case is plotted. The singularity of the plot is due to a limited number of frequency selection. With more frequency sampling, the smoother curve can be obtained. As shown in the figure, the overall curve tendency is maintained according to electrode size variation. The signal strength variation is less than 10 dB and it is because of different skin to the contact area. The overall bandwidth is maintained relative flatness up to high frequency range.

### 2.3 Channel Effect Measurement with Variable: GND Electrode Size

In the BCC, TX and RX GND planes are isolated and closed loop is modeled by capacitive coupling manner. Under the assumption of virtual earth GND, the ground node can be coupled directly or indirectly through the earth GND coupling. This indicates that not only larger forward path coupling (between TX signal electrode and RX signal electrode) but also larger return path coupling (between TX GND plane and RX GND plane) may increase channel gain. Figure 5 shows three classifications of electrode configuration in capacitive coupling BCC. Figure 5(a) shows the first configuration that both the signal electrode and GND electrodes attached to the body directly. In this case, the body is assumed as an impedance network and TRX signaling is modeled as a current driving method. However, since the low impedance GND electrode is attached very near to the human body, so that signal attenuation is relatively higher. Figure 5(b) shows approach without attaching GND electrode to the body. The GND coupling can be modeled as capacitive coupling through body and air. It has a benefit on low-power design since body channel decrease channel attenuation. On the other hand, channel status may suffer environmental variation since GND is opened. Figure 5(c) is the case of GND is embedded in PCB board. This approach mitigates the drawback of open GND, but careful design effort is required. In this measurement, open GND approach is utilized since it has more flexibility to adjust GND plane size.

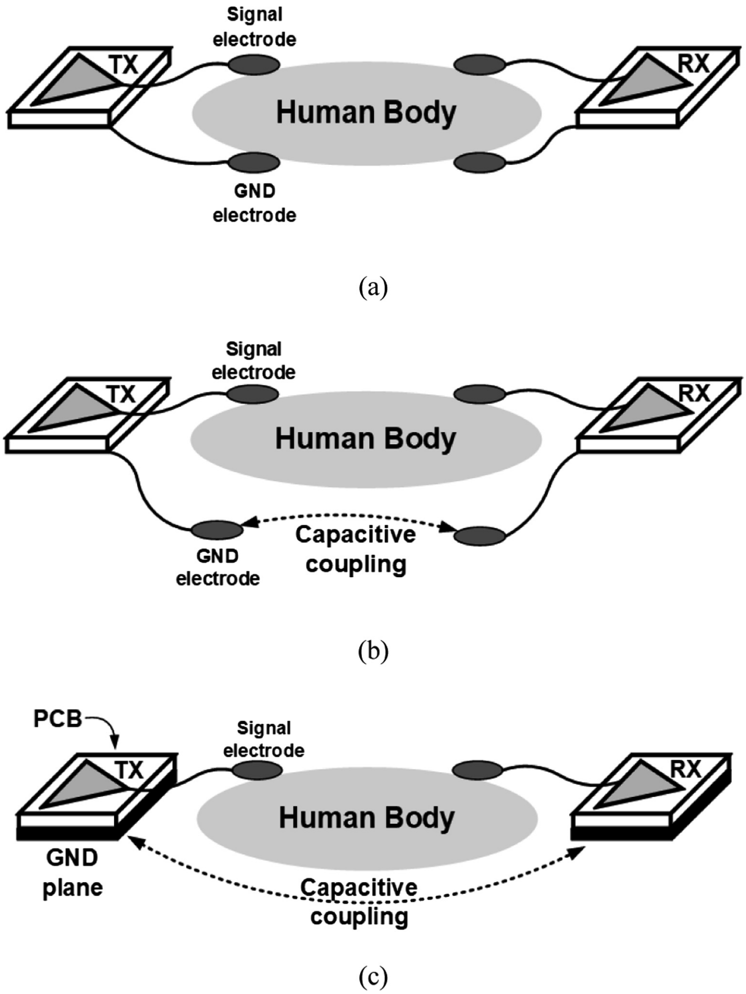
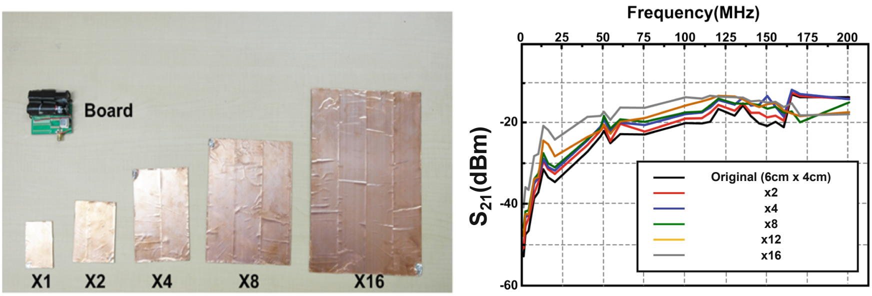


**Fig. 5.** Electrode configuration (a) Attaching signal and GND electrode. (b) Attaching signal electrode and floating GND electrode. (c) Signal electrode attaching and integrated GND plane in PCB



(a) (b)

**Fig. 6.** (a) Tested different size of electrodes and custom TX board (b) measured channel gain results

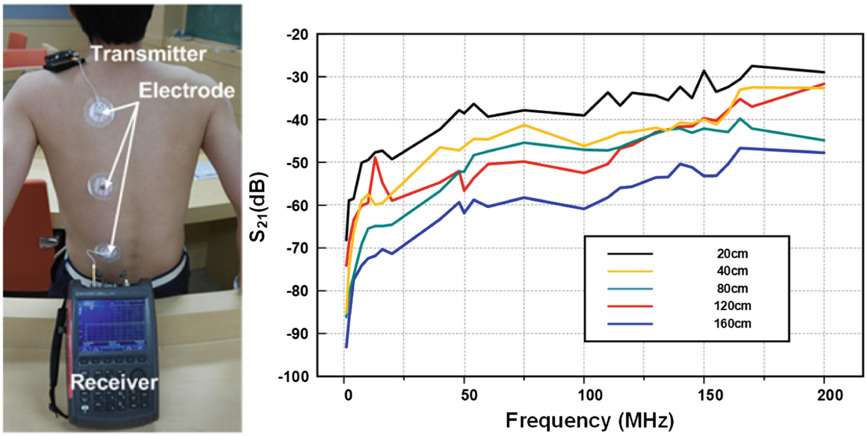
Figure 6(a) shows tested electrodes that are fabricated in a different size. With a basic customized TX board setup, the additional electrode is connected to the board GND plane through soldering. The basic GND electrode size is designed as 6 cm 4 cm and its size are varied up to 16 times larger GND plane size, as a maximum case consideration. Figure 6(b) plotted measured results. With the increase of GND plane size, the channel gain increase slightly, and overall channel gain variation is less than 10 dB. It induces that the return path coupling increase channel gain but its contribution does not affect linearly so that does not occupy the dominant portion. Also, the remarkable point is that the overall bandwidth is not affected by the GND plane size directly.

### 2.4 Channel Effect Measurement with Variable: Channel Distance

Figure 7(a) describes the measurement environment in the variation of channel distance. To reduce the effect of another parameter such as body position, from torso to leg part is chosen and the test body is fixed for measurement. The communication distance is varied from 20 cm to 160 cm distance, and the wet electrode is selected to improve reliable contact. The measured results are shown in Fig. 7(b). With the increase of communication distance, the overall signal attenuation increase linearly in the dB scale. The remarkable point is that still, the bandwidth does not vary according to communication distance. It can be concluded that the channel distance also does not a major factor to affect channel distance.

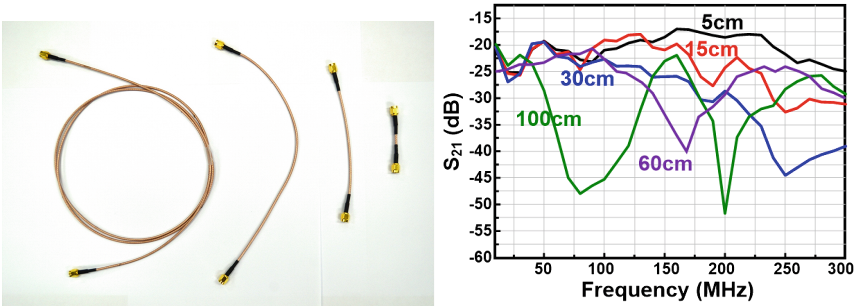
### 2.5 Channel Effect Measurement with Variable: Cable Length

Figure 8(a) shows the different size of cables. By varying connection cable length between electrode and transceiver, the effect of cable length is verified. The SMA shielded cable is used and its length is customized from 5 cm to 100 cm. The measurement results are shown in Fig. 8(b). As shown in the figure, the channel bandwidth is maintained up to 200 MHz within the case of 5 cm. However, with an increase of cable length, the channel fluctuation is accelerated, and in the case of 100 cm, the



(a) (b)

**Fig. 7.** (a) Measurement setup for distance variation effect (b) measured channel gain results



(a) (b)

**Fig. 8.** (a) Tested cables with different length (b) measured channel gain results

overall fluctuation is more than 30 dB range which is undesirable. There are two reasons for this phenomena. First, even though the cable is shielded by the metallic cover, non-linear signal radiation occurs through the long cable. Since such a cable is inherently twisted or bent, the radiation pattern induces non-uniform bandwidth pattern in the channel. Secondly, without impedance matching, certain standing wave pattern can be assumed through a long cable. Such a pattern can generate channel fluctuation and overall channel communication bandwidth is strictly limited. This result shows that the long cable between devices and electrode affect channel condition and on the other hands, it means that available bandwidth can be extended up to 200 MHz range in the case of short cable usage. Moreover, typical wearable and portable applications do not integrate such a long cable, the verified results can be generalized to overall BCC transceiver hardware design.

Increasing available channel bandwidth can be considered as a superior advantage in hardware design. Larger bandwidth directly connected to potential with increasing transceiver data rate and reduces the filtering overhead in the hardware design. However, there are other considerations in the BCC. Due to the presence of the body antenna effect, an external FM radio band from 80 MHz to 110 MHz acts as an interference in the communication. The contact status may affect the channel condition. In the case of stable contact, the signal path can be modeled as a resistive path. But in the case of separation, the signal path operates like a serial capacitive coupled path. So the additional signal attenuation may vary channel status. In spite of several design challenges, BCC can be advantageous as an efficient and low power communication solution. Note that such efforts are generally applied to the RF hardware design also. The influence of the cable and channel characteristics covered in this paper can give intuition and help for understanding the nature of BCC hardware design.

## 3 Conclusion

In this paper, multiple parameters that can affect channel characteristics is discussed. The previous research has limitation in channel bandwidth up to 100 MHz range due to channel fluctuation. 4 independent systemic factors are under test; (1) the size of signal electrode attaching on the skin, (2) the size of the ground plane (GND) electrode that is not attaching on the skin, (3) the channel distance between TX and RX through human body, and (4) the length of cable connecting between the transceiver hardware and signal electrode. The size of the electrode and channel communication does not have a high correlation with channel fluctuation. However, the cable length between electrode and device shows a large variation. The newly proposed results are useful for hardware design and allow larger utilizable channel bandwidth that is promising for future BCC hardware design.

## References

1. IEEE Computer Society: IEEE standard for local and metropolitan area networks: part 15.6 wireless body area networks. IEEE Standards Association. IEEE Computer Society. Accessed 29 Feb 2012
2. Bae, J., Song, K., Lee, H., Cho, H., Yoo, H.: A 0.24–nJ/b wireless body-area-network transceiver with scalable double-FSK modulation. IEEE J. Solid-State Circ. **47**(1), 310–322 (2012)
3. Jang, J., Bae, J., Yoo, H.: Understanding body channel communication. In: Custom Integrated Circuit Conference (2019)
4. Zimmerman, T.: Personal area networks (PAN): near-field intra-body communication. IBM Syst. J. **35**(34), 609–617 (1996)
5. Song, S.J., Cho, N., Kim, S., Yoo, J., Yoo, H.J.: A 2 Mb/s wideband pulse transceiver with direct-coupled interface for human body communications. In: 2006 IEEE International Solid State Circuits Conference - Digest of Technical Papers, San Francisco, CA, pp. 2278–2287 (2006)

6. Song, S., Cho, N., Kim, S., Yoo, J., Choi, S., Yoo, H.: A 0.9 V 2.6 mW body-coupled scalable PHY transceiver for body sensor applications. In: 2007 IEEE International Solid-State Circuits Conference. Digest of Technical Papers, San Francisco, CA, pp. 366–609 (2007)
7. Cho, N., Lee, J., Yan, L., Bae, J., Kim, S., Yoo, H.: A 60 kb/s-to-10 Mb/s 0.37nJ/b adaptive-frequency-hopping transceiver for body-area network. In: 2008 IEEE International Solid-State Circuits Conference - Digest of Technical Papers, San Francisco, CA, pp. 132–602 (2008)
8. Lee, J., et al.: 30.7 A 60 Mb/s wideband BCC transceiver with 150pJ/b RX and 31pJ/b TX for emerging wearable applications. In: 2014 IEEE International Solid-State Circuits Conference Digest of Technical Papers (ISSCC), San Francisco, CA, pp. 498–499 (2014)
9. Cho, H., Kim, H., Kim, M., Jang, J., Bae, J., Yoo, H.: 21.1 A 79pJ/b 80 Mb/s full-duplex transceiver and a 42.5 μW 100 kb/s super-regenerative transceiver for body channel communication. In: 2015 IEEE International Solid-State Circuits Conference - (ISSCC) Digest of Technical Papers, San Francisco, CA, pp. 1–3 (2015)
10. Song, S., Cho, N., Yoo, H.: A 0.2-mW 2-Mb/s digital transceiver based on wideband signaling for human body communications. IEEE J. Solid-State Circ. **42**(9), 2021–2033 (2007)
11. Cho, N., Yoo, J., Song, S., Lee, J., Jeon, S., Yoo, H.: The human body characteristics as a signal transmission medium for intrabody communication. In: IEEE Transactions on Microwave Theory and Techniques, vol. 55, no. 5, pp. 1080–1086, May 2007
12. Bae, J., Cho, H., Song, K., Lee, H., Yoo, H.: The signal transmission mechanism on the surface of human body for body channel communication. In: IEEE Transactions on Microwave Theory and Techniques, vol. 60, no. 3, pp. 582–593, March 2012
13. Bae, J., Yoo, H.: The effects of electrode impedance on receiver sensitivity in body channel communication. Microelectron. J. **53**, 73–80 (2016)