Wireless Bio-Signal Sensing System Using a Circular Polarized Antenna

Young-Bae Kwon[1] · Jung-Min Park[2] · Jung-Hwan Choi[3] · Seong-Ook Park[3] · Osami Ishida[3]

Abstract

Wireless bio-signal sensing system, which is based on the principle of Doppler radar, can measure a respiration and heart rates with a periodic movement of skin and muscle near the heart. Though the sensing monostatic system using a circulator has been studied, this bistatic system can be improved by using a circular polarized antenna which has a high isolation between transmitter and receiver. In this paper, we measured the bio-signal without the direct contact with the person. The design of each system and experimental results are discussed.

Key words : Wireless, Bio-Signal, Circular Polarization, Isolation.

Ⅰ. Introduction

One of the recent medical trends is a remote health-care system. With this trend, the parts of wireless sensing technology of respiration and heart rates have been studied by many laboratory members since 1975[1],[2].

The wireless medical sensing instrument using RF system is to profit in terms of the cost and easy to compare with expensive medical instruments. Since this sensing system does not require a direct contact with a person, it can be decreased a patient's psychical burden. Also, the sensing system can obtain the bio-signal of emergency patients who can not contact directly such as a skin burn.

In this paper, two systems are considered. One is the monostatic system using a circulator, the other is the bistatic system using a linear or a circular polarized antenna. Especially, the latter can be improved using a circular polarized antenna which has a high isolation between transmitter and receiver rather than an established sensing monostatic system. Each system is consisted of an antenna, RF transceiver(transmitter and receiver), and baseband section which is extracting a wave information of respiration and heart rates.

Ⅱ. Analysis of the Sensing System

2-1 Operating Principle of the System

The wireless bio-signal sensing system which can measure a weak bio-signal is based on the principle of Doppler radar[3].

If the target has a velocity toward or backward the direction of the radar, the reflected signal from the surface of moving target is shifted in frequency in proportion to the velocity of target. The skin and the muscle near the heart are an object of measurement in the sensing system. That is, the wireless bio-signal sensing system can measure a respiration and heart rates with a periodic movement of skin and muscle near the heart.

At 10 GHz, the dielectric constant and conductivity of skin and muscle near the heart is listed in Table 1[4]. As shown in Table 1, since the skin and muscle have a high dielectric constant and conductivity, the penetration depth of radiated signal is rapidly attenuated in the outer tissue. And the reflected signal from the heart is measured by this wireless sensing system. The received signal is properly amplified by LNA and entered into the mixer with the LO signal. Then the IF signal is filtered by band-pass filter and monitored a wave information within 0.33~0.5 Hz for respiration, 0.6~3.3 Hz for heart rates[5].

2-2 Analysis of the System

A block diagram of the wireless bio-signal sensing monostatic system is shown in Fig. 1. The source power of system is 11 dBm. This source signal divided by the

Table 1. The dielectric constant and conductivity of human skin and muscle.

	Dielectric constant		Conductivity(S/m)	
	Skin	Muscle	Skin	Muscle
10 GHz	31.29	42.764	8.0138	10.626

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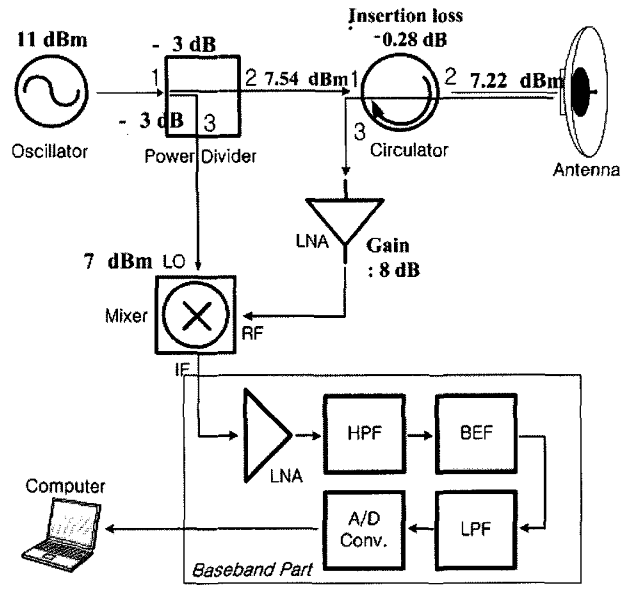


Fig. 1. The block diagram of wireless bio-signal sensing monostatic system.

power divider. One of them is entered to the LO port of mixer with 7 dBm which is included the cable loss 1 dB, the other is entered to the antenna through the circulator with 7.22 dBm which is included to the cable loss 0.46 dB, the insertion loss of circulator 0.28 dB, and the connector loss 0.04 dB. The radiated signal from the antenna is reflected to the chest, and it is received the same antenna. This received signal power is −23∼−19 dBm at the port 3 of circulator. The output signal of circulator is amplified in the LNA that has a gain 8 dB. This signal is entered the RF port of mixer and mixed LO signal.

In this system, the isolation of circulator is about −22 dB and shown in Fig. 2. This isolation characteristic is limited to the dynamic range in the overall system. That

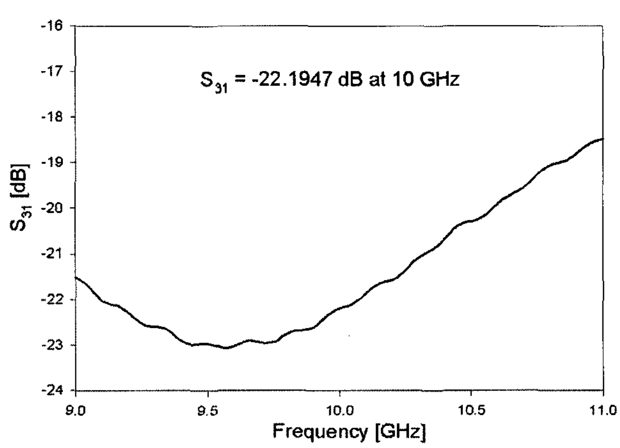


Fig. 2. The isolation of the circulator(S_{31}).

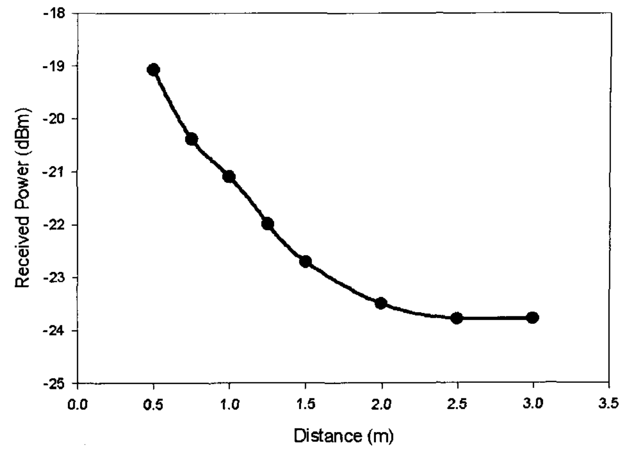


Fig. 3. The received power of circulator at port 3 with changing the distance between the antenna and person.

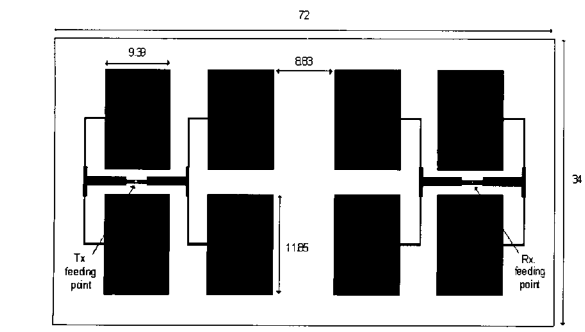
is, the signal below −22 dBm can not distinguish whether by port 1 or by the reflected signal from the person. In Fig. 3, the received power of circulator at port 3 is measured with changing to the distance between the antenna and person. If the distance between the antenna and person is over 2.5 m, the received power is almost not varied. Since the isolation of circulator has a limitation, the signal at port 1 is also delivered to the port 2 but the port 3. This inevitable signal degrades a dynamic range of monostatic system. So, it is needed to improve the isolation of monostatic system.

2-3 Antenna Model

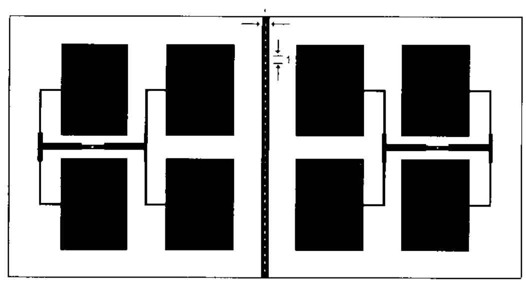
To solve the problem of monostatic system, the bistatic system is proposed. The transmitted antenna and the received antenna are used separately without a circulator. The four antenna models are considered. The commercial program HFSS based on the finite element method(FEM) and Ensemble based on the method of moments(MoM) are used for analyzing the behavior of proposed antenna model and determining suitable values of parameters. The proposed antennas are etched on the Duroid 5880 substrate with the thickness of 0.508 mm, relative permittivity of 2.22 and the size of substrate is 72 mm×34 mm. A 50 Ω coaxial probe is connected vertically to feed this proposed antenna.

2-3-1 Linear to Linear Polarized Antenna

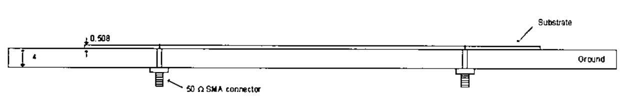
The linear to linear polarized antenna is shown in Fig. 4. The transmitted and the received antenna with linear polarization are placed on the same substrate. In Fig.



(a) Without via hole



(b) With via hole



(c) Side view

Fig. 4. The linear to linear polarized antenna.

4(b), the via hole is proposed as an idea that the via hole between the Tx. and Rx. antenna can reduce an interference caused by a surface wave in the microstrip patch antenna[6]. That is, the unwanted signal which is the signal at port 2 delivered by port 1 can be reduced. Therefore, the isolation is able to be improved. The measured return loss and the isolation of the linear to linear

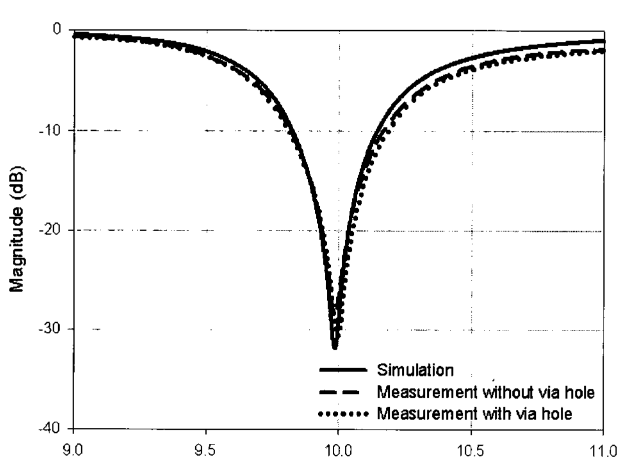


Fig. 5. The simulated and measured return loss of linear to linear polarized antenna.

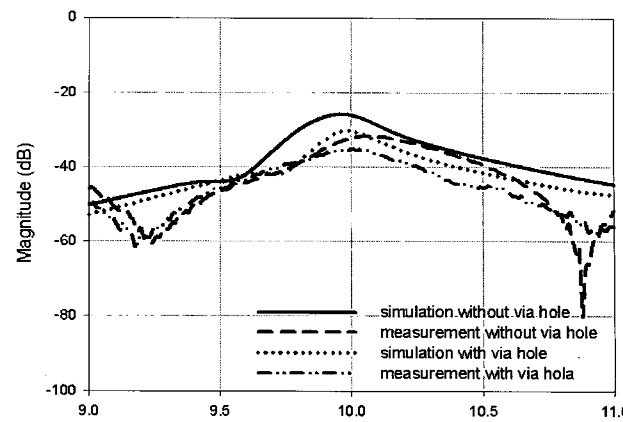
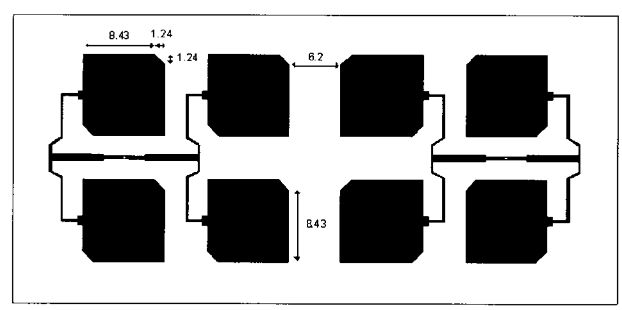
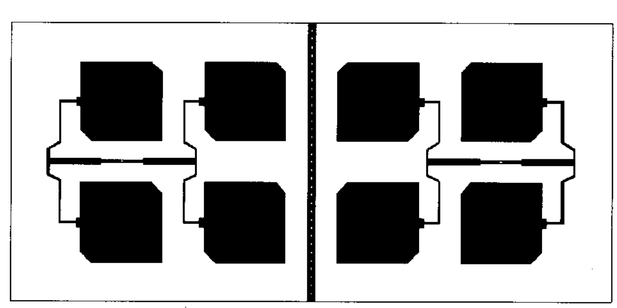


Fig. 6. The simulated and measured isolation of linear to linear polarized antenna(S_{21}).

polarized antenna are shown in Fig. 5 and Fig. 6. As Fig. 5, the return losses do not be effected about the via hole. The isolation of linear to linear polarized antenna is −32.41 dB without via hole and −35.45 dB with via hole at 10 GHz. The model with via hole is obtained to a better isolation about 3 dB. It can be considered to reduce interference each other. These results are improved considerably than the monostatic system with isolation −22.2 dB in Fig. 2. So, the dynamic range of bistatic system can be wider than the monostatic system. The half power beamwidth and the antenna gain are obtained 43° and 12.12 dBi, respectively.



(a) Without via hole



(b) With via hole

Fig. 7. The left-hand and right-hand circular polarized antenna.

2-3-2 Left-hand to Right-hand Circular Polarized Antenna

The left-hand and right-hand circular polarized antenna is shown in Fig. 7. A circular polarized antenna is considered due to a large polarization loss between left-hand circular polarization and right-hand circular polarization, a high dielectric constant and conductivity of body at 10 GHz.

As the linear to linear antenna model, this antenna is measured without and with via hole. The measured and simulated return loss of the circular polarized antenna without and without via hole are shown in Fig. 8. And the measured and simulated axial ratio of the circular polarized antenna without via hole are shown in Fig. 9. Also the isolation of left-hand to right-hand circular polarized antenna is illustrated in Fig. 10.

In Fig. 10, the isolation is −39.88 dB without via hole and −43.69 dB with via hole at 10 GHz. The model with via hole is obtained a better isolation about 4 dB. These results are improved than the linear to linear polarized antenna with isolation −35.45 dB in Fig. 6. The half power beamwidth and the antenna gain are obtained 36° and 11.83 dBi, respectively.

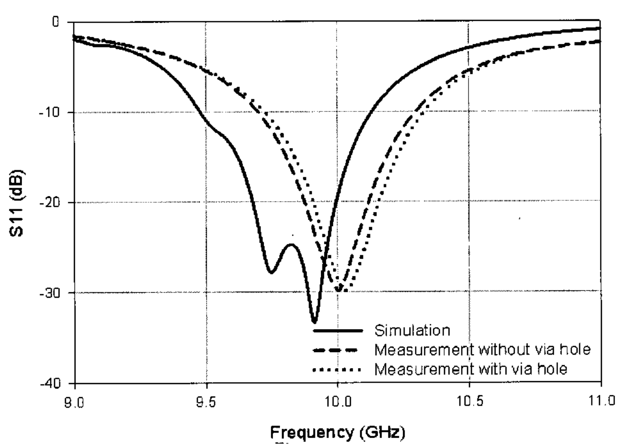


Fig. 8. The measured return loss of circular polarized antenna.

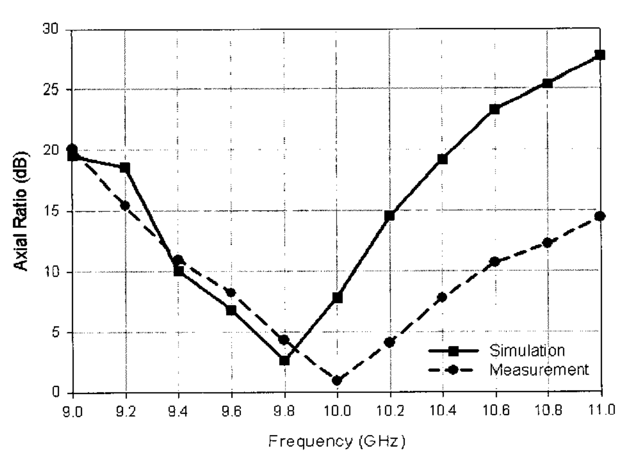


Fig. 9. The measured axial ratio of circular polarized antenna without via hole.

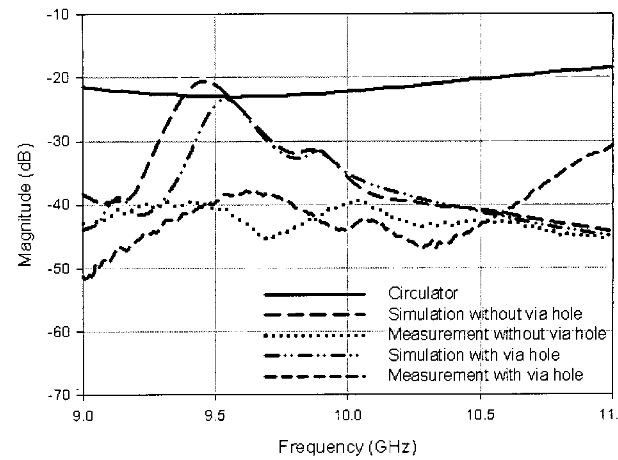


Fig. 10. The measured isolation of left-hand to right-hand circular polarized antenna.

2-3-3 Left-hand to Left-hand Circular Polarized Antenna

The left-hand to left-hand circular polarized antenna and the right-hand to right-hand circular polarized antenna are used to compare with the characteristic of the left-hand to right-hand circular polarized antenna. A left-hand and left-hand circular polarized antenna is shown in Fig. 11.

2-3-4 Right-hand to Right-hand Circular Polarized Antenna

A right-hand and right-hand circular polarized antenna

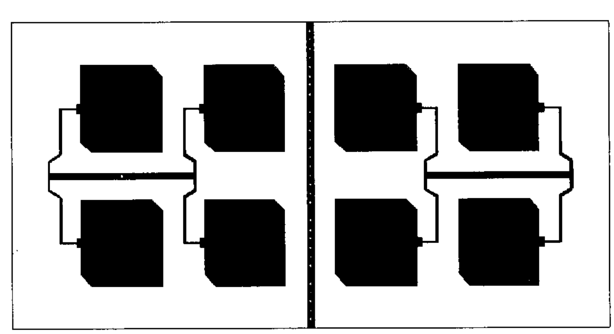


Fig. 11. The left-hand and left-hand circular polarized antenna.

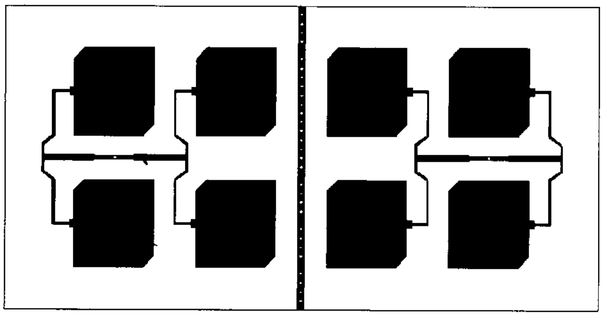


Fig. 12. The right-hand and right-hand circular polarized antenna.

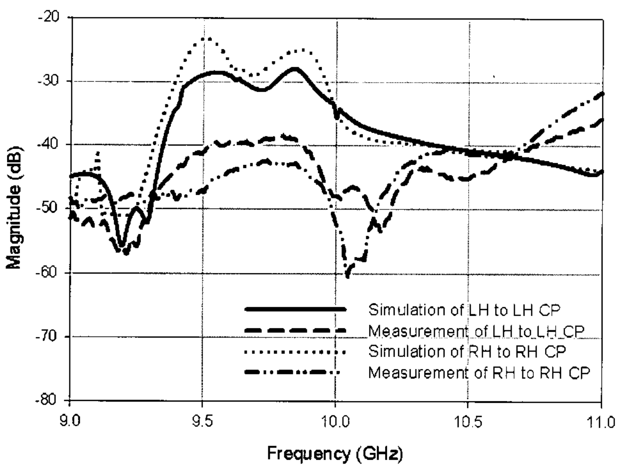


Fig. 13. The measured isolations of left-hand and left-hand circular and right-hand to right-hand polarized antenna.

is shown in Fig. 12. The measured isolations of left-hand to left-hand and right-hand to right-hand circular polarized antenna are shown in Fig. 13. Though these models have a good isolation between Tx. and Rx. antenna, they have a disadvantage in the bio-signal sensing system due to a large polarization loss.

As the isolation of each model is measured, the left-hand to left-hand and right-hand to right-hand circular polarized antenna is shown a good characteristic

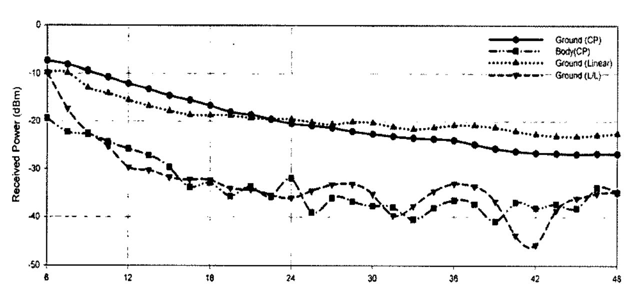


Fig. 14. The received power with changing to the distance.

−43.6902 dB. Since linear to linear antenna has a −35.4508 dB isolation, the dynamic range is limited than the left-hand to right-hand circular polarized antenna.

In Fig. 14, the received power is measured with changing to the distance between the antenna and body, the antenna and ground. The default distance between an antenna and an object is 6 cm. The received power with changing to the distance is related to oneself isolation and polarization loss. The circular polarization of a reflected signal from ground or body is changed on the contrary. The same circular polarized antenna has a large polarization loss, the received power is very small. So, the left-hand to right-hand circular polarized antenna is an optimum result in wireless bio-signal sensing system because of a large dynamic range and good isolation. When the received power of left-hand to right-hand circular polarized antenna is measured between antenna and body, the power is drastically dropped as compared with between antenna and ground. Though the body has a high conductivity and dielectric constant at 10 GHz, the body is not a perfect conductor. So, the polarization loss is happened. Also, since the body is not horizontal to an antenna, the reflected power can not return entirely.

2-4 Bistatic System Using a Circular Polarized Antenna

A block diagram of the wireless bio-signal sensing

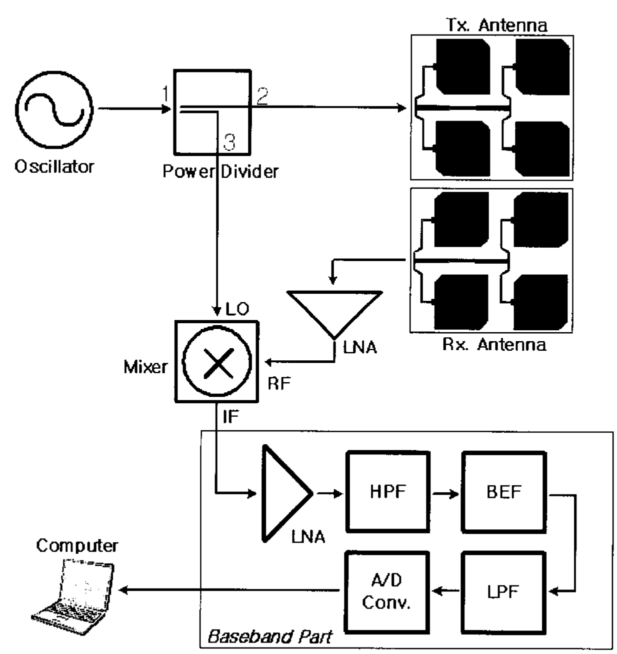


Fig. 15. The block diagram of wireless bio-signal sensing bistatic system.

bistatic system using a circular polarized antenna is shown in Fig. 15. This system uses two circular polarized antennas instead of implementing with a conventional circulator. The transmitted antenna has a left-hand circular polarization(LHCP) and the received antenna has a right-hand circular polarization(RHCP).

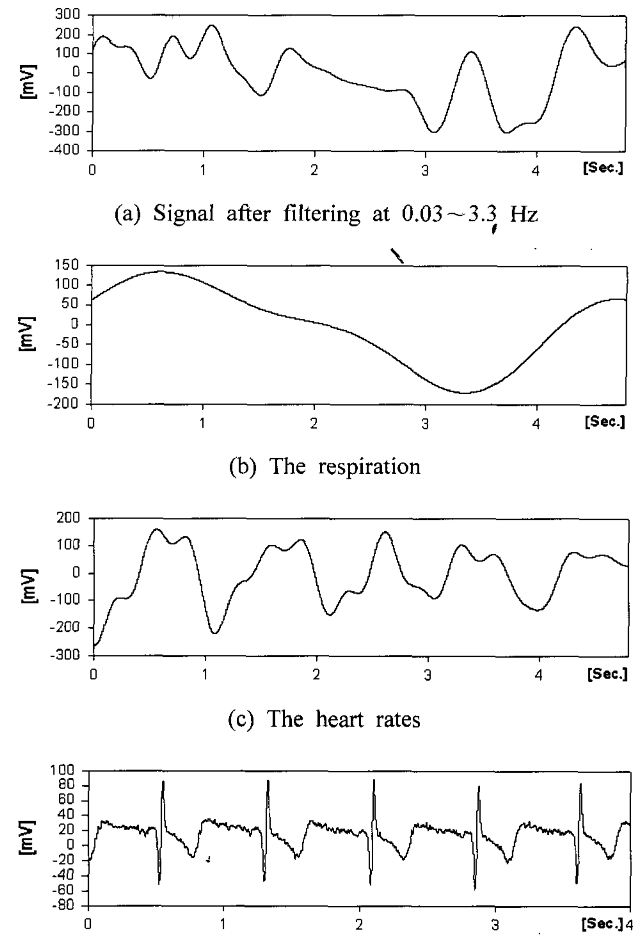
Theoretically, the LHCP antenna can transmit and receive the signal which has a LHCP without a polarization loss and the RHCP antenna is same. If a LHCP is reflected to the ideal conductor, a LHCP is changed to a RHCP[7]. Also, since human skin and muscle have a high conductivity at 10 GHz in Table 1, this sensing system transmits a LHCP signal and receives a RHCP signal reflected at a skin and muscle near hearts with a small polarization loss.

In this system, the left-hand to right-hand circular polarized antenna is used because left-hand to right-hand circular polarized antenna has a better isolation than the linear to linear polarized antenna and a smaller polarization loss than the left-hand to left-hand circular polarized antenna and the right-hand to right-hand circular polarized antenna. The bistatic system using a left-hand to right-hand circular polarized antenna is improved to a dynamic range and isolation due to a change of polarization caused by a high conductivity and dielectric constant of human at 10 GHz.

2-5 Measured Results

The measured results of respiration and heart rates at 0.5 m in the monostatic system are shown in Fig. 16. Fig. 16(a) is shown as the signal which is filtered off the output of IF signal at 0.03~3.3 Hz in baseband part. To obtain the respiration, the output of IF signal is filtered in 0.03~0.5 Hz in Fig. 16(b), and Fig. 16(c) is shown as the heart rates filtered in 0.6~3.3 Hz[8]. Finally, Fig. 16(d) is an electrocardiogram signal used in the hospital. Since the signals of heart rates and electrocardiogram signal have an agreement each other, these results are able to credit.

The respiration and heart rates which measured in-wireless bio-signal sensing bistatic system are shown in Fig. 17~18. Fig. 17 shows the measured results of the bistatic system with linear to linear polarized antenna at 10 GHz. And Fig. 18 shows the measured results of the bistatic system with left-hand to right-hand polarized antenna at 10 GHz. Each figure shows the output of IF signal at 0.03~3.3 Hz, the respiration, heart rates, and electrocardiogram(ECG) signal. It can be known that the bistatic system with left-hand to right-hand polarized antenna has better performance than the bistatic system with linear to linear polarized antenna because the



(a) Signal after filtering at 0.03~3.3 Hz

(b) The respiration

(c) The heart rates

(d) Electrocardiogram(ECG) signal

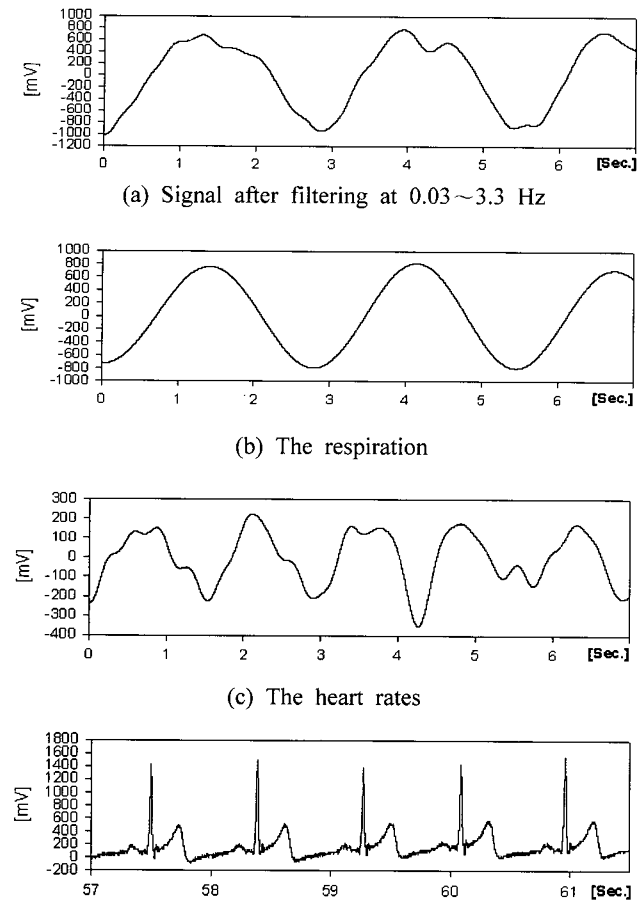
Fig. 16. The measurement result in the monostatic system at 10 GHz.

isolation has been improved by using a circular polarized antenna.

The results of respiration and heart rates are measured with a distance of 50 cm from the person in the bistatic system. The movement by a respiration is dominated than by heart rates in the chest. So, the respiration can obtain a more pure waveform. All models can sense a heart rates and respiration, and these results can credit because heart rates and ECG have a good agreement. But the left-hand to left-hand and right-hand to right-hand circular polarized antenna is sensed a weak signal due to a large polarization loss.

Ⅲ. Conclusions

The wireless bio-signal sensing bistatic system using the circular polarized antenna has a wider operating rage than the monostatic system due to the better isolation. The isolation of the monostatic system is about −22 dB at 10 GHz, while the isolation of the bistatic system



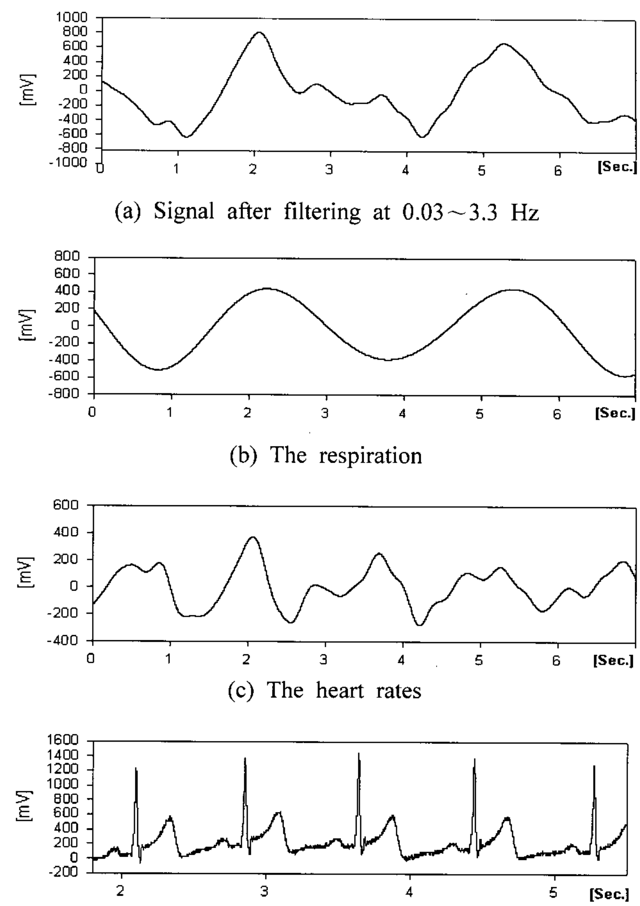
(a) Signal after filtering at 0.03~3.3 Hz

(b) The respiration

(c) The heart rates

(d) Electrocardiogram(ECG) signal

Fig. 17. The measurement result in the bistatic system with linear to linear polarized antenna at 10 GHz.



(a) Signal after filtering at 0.03~3.3 Hz

(b) The respiration

(c) The heart rates

(d) Electrocardiogram(ECG) signal

Fig. 18. The measurement result in the bistatic system with left-hand to right-hand polarized antenna at 10 GHz.

with the left-hand to right-hand circular polarized antenna is about −43.69 dB at 10 GHz. Also, it can reduce the unwanted noise by using the cross polarization in the transmitter and receiver. In this paper, we obtained that the respiration is 0.2~0.3 Hz(12~18 breaths/min.) and the heart rates is 0.9~1.6 Hz(54~96 beats/min.).

The wireless bio-signal sensing bistatic system has many applications such as a remote medical examination, portable bio-signal sensing system within PCS cellular phone, decision either life or death of buried person, and observation of invaders.

References

[1] J. C. Lin, J. Salinger, "Microwave measurement of respiration", *IEEE MTT-S International*, vol. 75, pp. 285-287, 1975.

[2] J. C. Lin, J. Kiernicki, M. Kiernichi, and P. B. Wollschaeger, "Microwaveapexcardiography", *IEEE Transactions Microwave Theory and Technique*, vol. 27, pp. 618-620, 1979.

[3] A. Droitcour, V. Lubecke, Lin Jenshan, and O. Boric-Lubecke, "A microwave radio for Doppler radar sensing of vital signs", *IEEE MTT-S International*, vol. 1, pp. 175-178, 2001.

[4] C. Gabriel, S. Gabriel, and R. W. Lau, "The dielectric properties of biological tissues", *Phys. Med. Biol. 41*, pp. 2231-2293, 1996.

[5] J. C. Lin, *Electromagnetic Interaction with Biological Systems*, Plenum Press, New York, 1975.

[6] R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House, pp. 43, 2001.

[7] C. A. Balanis, *Advanced Engineering Electromagnetics*, John Wiley & Sons, pp. 236, 1989.

[8] K. H. Chan, J. C. Lin, "Microprocessor-based cardiopulmonary rate monitor", *Medical & Biological Engineering & Computing*, vol. 25, pp. 41-44, 1987.

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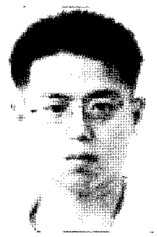

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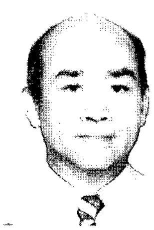

He was born in Mikkabi, Japan on August 25, 1948. He received the B.S. and M.S. degrees in electronic engineering, and the Dr. Eng. degree from the Shizuoka University, Hamamatsu, Japan, in 1971, 1973, and 1992, respectively. In 1973, he joined the Mitsubishi Electric Corporation, Kamakura, Japan, where he had been a manager in the aperture antenna group (1988~1992), deputy manager in the opto & microwave electronics department(1993~1995), manager in the microwave electronics department(1995~2001), and was a general manager in the electro-optics & microwave systems laboratory at the Information Technology R&D Center(2001~2004). He had been engaged in the research and development of microwave-circuit technologies in antenna feeds for satellite communication and phased-array radars, and in devices for mobile communication. From 1992 to 1998, he led R&D projects of microwave devices for small and light handsets of cellular telephone. He is currently an invited professor of the Information and Communications University, Daejeon, Korea since March 2004. Dr. Ishida is a Fellow of the Institute of Electrical and Electronics Engineering(IEEE) and a member of the Institute of Electronics, Information, and Communication Engineering(IEICE), Japan.