X-band Radar System for Detecting Heart and Respiration Rates

Jee-Hoon Lee, Yun-Taek Im, and Seong-Ook Park

Korea Advanced Institute of Science and Technology, Daejeon, Korea

***Abstract*—This paper proposes an X-band Doppler radar system to detect heart and respiration of human far away. Through the idea of a reverse sense of rotation when the reflecting surface is perfectly conducting, it is shown that the detecting property of the system can be effectively improved by using antennas that have a reverse polarization. This bistatic radar system can be used in non-invasively sensing bio signals such as respiration and heart rates with the periodic movement of skin and muscle near the heart.**

Keywords-heart rate; X-band; array antenna; polarization;

I. INTRODUCTION

Wireless bio-signal detection is the recent tendencies in the medical industry, and research for sensing bio-signal continues to rise. The remote sensing of person using RF system is profitable in cost aspects compared with expensive medical instruments. Because the sensing system is easy to handle, even ordinary person who is not instructed about usage of the instruments can use it. Until now, bio-detecting system can measure within short range. We proposed radar system to detect heart and respiration rates of human 10m away from antenna using a high gain array antenna and a frequency synthesizer which has a low phase-noise characteristic.

II. RADAR SYSTEM

A. The Basic Concept of the System

The configuration of X-band Doppler radar system is shown in Figure 1. To improve isolation between transmitter and receiver, we have separated Tx and Rx antenna. For metallic target, circularly or elliptically polarized waves are reflected back after changing the polarization sense. In a dielectric material, circularly polarized waves are reflected back, changing the axial ratio as well as its sense, which eventually causes polarization mismatch if Tx and Rx antennas have opposite polarization sense [1]. This is a useful method to eliminate noise-like targets in the microwave detection system when the main target is a metallic object. CP waves are not always required to discriminate targets, but elliptically polarized waves can also be used to sort targets [2]. According to these principles, we can achieve better sensitivity of the radar system using the opposite polarization of transmitting antenna and receiving antenna.

The radar system consists of a frequency synthesizer, power divider, mixer, and low noise amplifier (LNA). The frequency synthesizer output power at an operating frequency of 10 GHz is 8 dBm. This source signal is divided using a power divider. One of them is applied to the LO port of the mixer with about 4.5 dBm, which includes the line loss, and the other is entered into the RHP antenna after power amplifier whose gain 20dB. The received signal is amplified in the LNA, which has a gain of 9 dB and a 3.3 dB noise figure. This signal is entered into the RF port of the mixer and mixed with the LO signal. Finally, Doppler frequency is entered to baseband part. We can check the power level at each block including the transmitted and received power at the antennas varying with the distance between antenna and target.

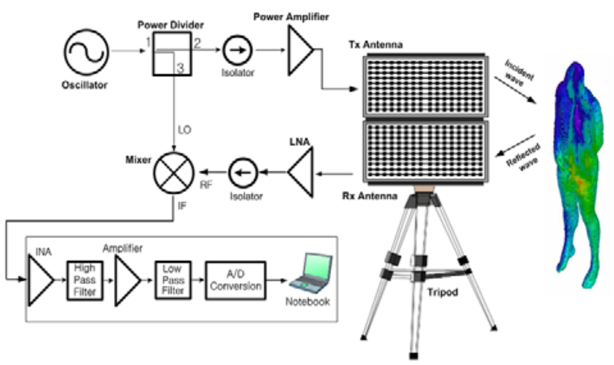

Figure 1. The block diagram of CW Doppler radar system.

In the baseband part, the IF signals are amplified in the instrumentation amplifier (INA), and the HPF then removes the DC in order to prevent a DC offset. The high frequency included in the IF signal is then filtered out at the LPF, and the signal is displayed on the computer after converting the digital signal at the A/D converter.

B. Series-fed Array Antenna

A series-fed elliptically polarized array antenna is designed for X-band radar system. Symmetrical series feeding at the array antenna center and truncated patches are applied to reduce side lobe levels (SLL) by modeling the array factor. Radiation from the feeding line is another source of side lobe degradation although it has a small effect. Thus, the feed line should be as short as possible. The feeding point is positioned at the array antenna center to minimize radiation from it. Figure 2 shows the antenna feeding arrangement and the structures. The design parameters are listed in Table 1. The inter element spacing (D1 and D2) are about 0.7 λ_0 so as to maintain the same phase condition. The center spacing is $\lambda_g/2$ to ensure the same input impedance in the left series and right series. Figure 2(a) and (b) show the center feed structure with a matching stub in a two-dimensional series feed array. A truncated patch element for a polarized wave is shown in Figure 2(c).

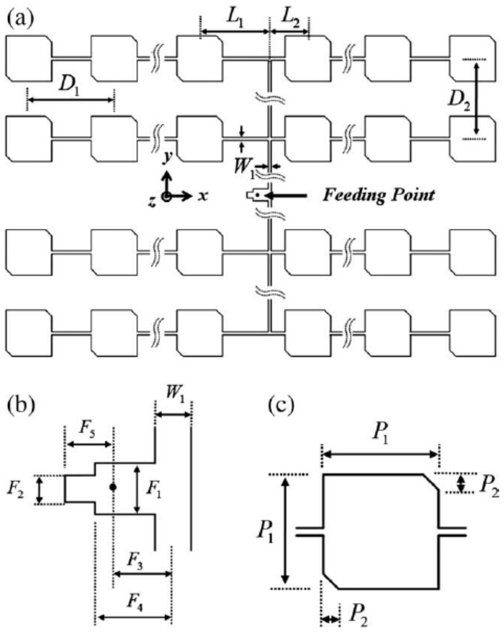

Figure 2. (a) Proposed array antenna structure (b) feed point with a matching stub (c) series-fed patch

TABLE I. DESIGN PARAMETERS (mm)

D1	D2	L1	L2	W1	F1
20.5	21.5	20.375	10.125	1.5	3
F2	**F3**	**F4**	**F5**	**P1**	**P2**
2	5	6	3	9.8	1.28

Figure 3 shows the fabricated antennas. It is fabricated on a substrate with a dielectric constant 2.2 and a thickness of 0.508 mm. The measured gain is 24.8 dBi. The SLLs are -16 and -19 dB in the zx-plane (ϕ=0°) and the yz-plane (ϕ=90°). The measured axial ratio is shown in Figure 4(d). The bandwidth is more than 2% at 10 GHz as shown in Figure 4 (c).

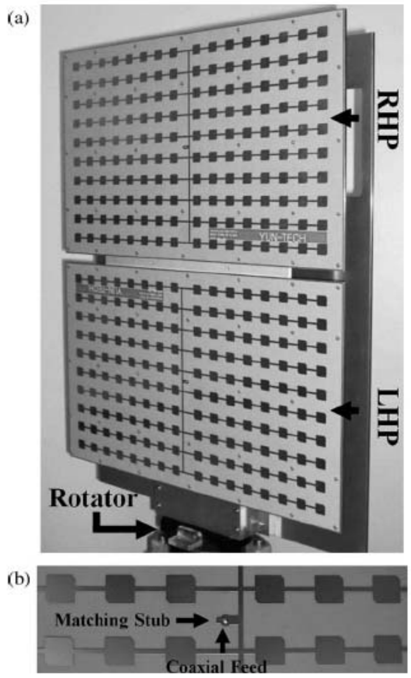

Figure 3. The fabricated antenna (a) RHP and LHP antenna (b) the center feed point with the matching stub

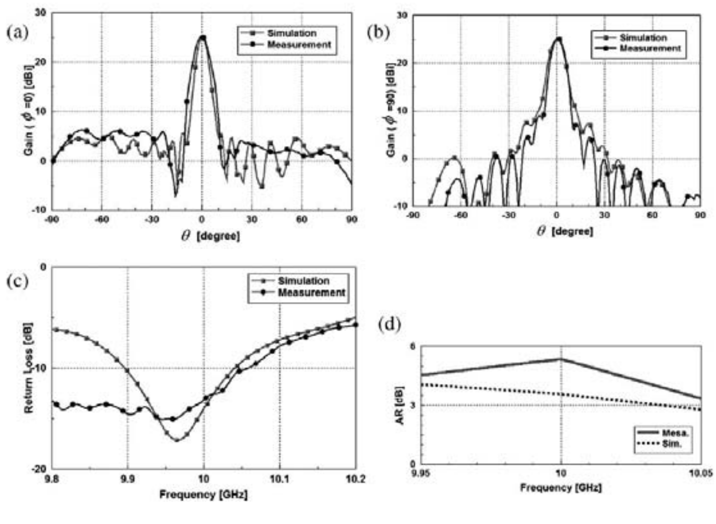

Figure 4. Simulation and measurement
(a) zx-plane (ϕ=0°) (b) yz-plane (ϕ=90°) (c) returen loss (d) axail ratio

C. Frequency Synthesizer

Phase noise is the important specification of a Doppler radar system. Since the motion signal is modulated on the carrier as a phase modulation, phase noise manifests itself as amplitude noise on the output. So, a frequency synthesizer which has a low phase noise characteristic has been proposed. Figure 5 shows the block diagram of frequency synthesizer.

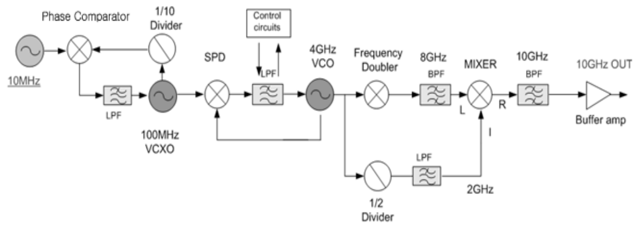

Figure 5. The block diagram of frequency synthesizer.

TABLE II. SPECIFICATION OF FREQUENCY SYNTHESIZER

Output Frequency	10GHz	Phase Noise	
		Offset	Typical
Output Power	5.5dBm	100MHz	-78 dBc/Hz
Harmonic Level	-20 dBc	1kHz	-93 dBc/Hz
Spurious Level	-80 dBc	10kHz	-105 dBc/Hz
Operating Power	12V, 450mA	100kHz	-120 dBc/Hz

III. MEASUREMT RESULTS

The male, 30 years in age, sat on a chair with clothing on, maintaining a straight posture. The antenna was located 10m away, focusing on the chest. In Figure 6, the top trace is the respiration signals, the second trace is the heart signals. Unit of x-axis is time [sec] and unit of y-axis is voltage [mV]. We can obtain the respiration and heart signals after filtering the raw signal within 0.03-0.6 Hz and 0.6-3.3 Hz, respectively. By comparing the heart rates with the ECG signal' peak position, we can verify that the period of the ECG's peak time is consistent with the heartbeat.

IV. CONCLUSIONS

The wireless bio-signal detection system has many applications such as remote medical examination, portable vital sign sensing within cellular phone, decision either life or death of buried person, detection of invader, etc [4]. In this paper, we verified the efficiency of the Doppler radar system using polarization selective series-fed array antennas and measured the respiration and heart rates. This system can potentially be used in ubiquitous home networking including remote medical examinations and treatment.

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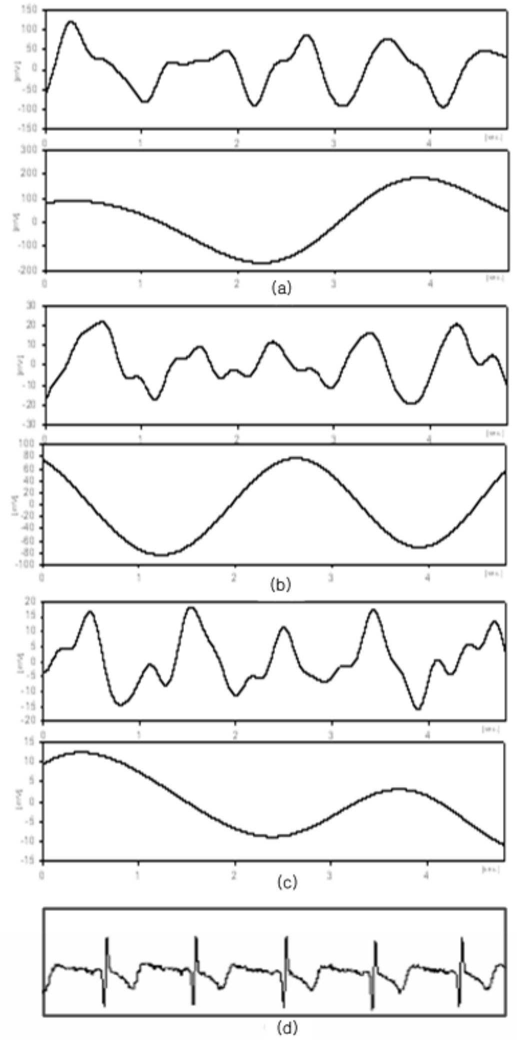

Figure 6. The measured respiration and heart rates form body to antenna (a) 5m distance (b) 7m distance (c) 10m distance (d) ECG signal

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