Feasibility Study for Non-Contact Heartbeat Detection at 2.4 GHz and 60 GHz

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Abstract

Two new schemes for human non-invasive cardiopulmonary activity monitoring are demonstrated using microwave low power and non-contact Doppler sensors. The two systems, using direct conversion architecture and simple design, are demonstrated and tested at a distance of 1 m from the patient. The first one proposes a simple technique for direct measurement of heartbeat signal at 2.4 GHz while the second scheme improves detection sensitivity when operating at 60 GHz.

1. Introduction

Traditional electrocardiogram (ECG) measurements with fixed electrodes are not practical in some cases like infants at risk of sudden infant death syndrome or burn victims. As the demand for remote monitoring solutions has increased in order to improve the quality of life for patients who need long hospitalization periods, more attention has been given to microwave Doppler radar for the remote monitoring of human health signals [1]. A person's chest has a periodic movement with no net velocity, and according to Doppler theory, reflects the transmitted signal with its phase modulated by the time-varying chest position [2]. As shown in Equation (1), the phase $\theta(t)$ of the reflected signal will be directly proportional to the chest position $x(t)$ that contains information about movement caused by heartbeat and respiration.

$$\theta(t) = \frac{4\pi x(t)}{\lambda} \tag{1}$$

In the above equation, λ is the wavelength of the transmitted waves. The average range of the peak-to-peak chest motion due to respiration is between 4 mm and 12 mm, whereas the chest displacement due to heartbeat alone is about 0.3 mm [3]. The measurement of this small displacement is the objective of this work and we are proposing the use of non-contact Doppler sensors for the remote monitoring of such signals.

In 2004, direct-conversion Doppler radars, operating at 1.6 and 2.4 GHz, have been integrated in 0.25 µm CMOS and BiCMOS technologies. The 2.4 GHz radar, placed at 50 cm range, uses a quadrature (I/Q) receiver. The use of a quadrature receiver improved the lowest accuracy form 40% to 80%. There has been additional recent work in using existing wireless communications infrastructure. A modified Wireless Local Area Network PCMCIA card and a module combining the transmitted and reflected signals were used to detect heart and respiration activity in [4]. A low-power double-sideband transmission in the Ka-Band was used in 2006 [5-6].

In this paper, we present two possibilities for non-contact heartbeat detection using direct conversion Doppler radars operating at 2.4 GHz and 60 GHz at a distance of 1 m from the patient. When breathing normally, the reflected signal off the target contains information about chest displacements due to heartbeat and respiration. For feasibility reasons, experiments are made while holding the breath. A low power, 2.4 GHz Continuous Wave (CW) signal is generated and the detection of the shifted phase between the received and the transmitted signals is performed. The shifted phase contains information about movements due to heartbeat. In order to increase the accuracy of the measured signal, another system operating at 60 GHz is also evaluated in this work. This frequency is chosen for several advantages over previously reported systems operating at other microwave frequencies. The first reason is that at 60 GHz, the transmitted signal has no interference with other applications. Moreover, this band is free for use in medical applications while the 2.4 GHz frequency band, for example, is occupied by many applications such as WLAN, Bluetooth, cordless phones etc… Another important reason is that as the frequency gets high, the wavelength gets smaller and the phase variation of the reflected signal increases [5, 7]. Hence, increased sensitivity to small displacements is obtained. This will improve the accuracy in detecting the R-R interval of the heart. Note that the R-R interval is the duration of ventricular cardiac cycle. Finally, the shorter the wavelength, the smaller the antennas needed to be integrated. The two systems operating at 2.4 and 60 GHz are presented in sections 2 and 3 respectively and the conclusion is stated in section 4.

2. 2.4 GHz Doppler sensor for heartbeat detection

The objective of the 2.4 GHz system is to perform a study using direct measurements with only a Vector Network Analyzer (VNA) and two antennas. The HP 7853D Network Analyzer provides a 2.4 GHz and 0 dBm continuous wave driven to a 10 dB gain Model 3115 Double-Ridged Waveguide Horn Antenna directed to a human chest positioned at 1 m. The reflected signal, received by another similar antenna, is driven to the VNA where the phase is calculated. 1601 measurement points are taken in a window of 10 seconds. Hence, a 160 Hz sampling frequency is obtained which is sufficient to produce accurate measurements. It is noteworthy to mention that the range of the heart rate is between 60 and 120 beats per minute; in other words, heart-beat frequency ranges from 1 to 2 Hz. Values are collected and transmitted via a GPIB cable to a PC where the Matlab software is used for processing the recorded data. Figure 1 shows the result for the heart-beat detection where the phase shift varies from 2° to 3°. The maximum-to-maximum delay shown in this figure represents the R-R interval, i.e. each maximum corresponds to a beat. For this experiment, the average heart rate is about 72 beats per minute.

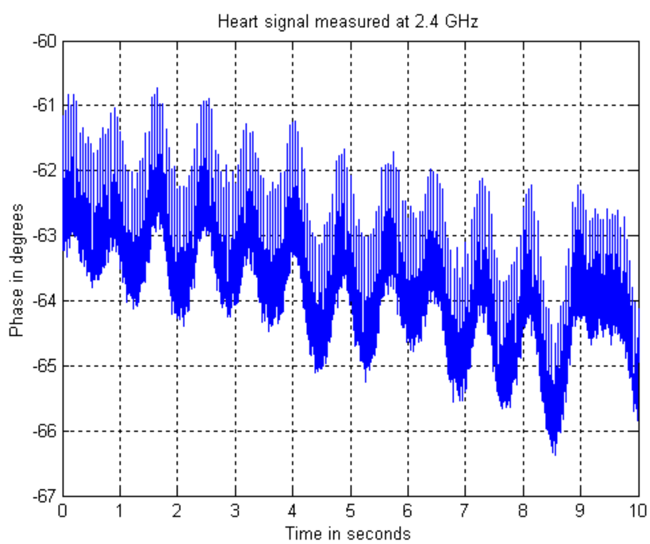

Figure 1 Heart activity detected at 2.4 GHz and 1 m from the patient

3. The 60 GHz measurement system

The system operating at 60 GHz is shown in Figure 2 and its components specifications are given in Table 1. The Phase Locked Oscillators (PLO) are driven by a 70 MHz synthesizer in order to generate 56.5 GHz. The 3.5 GHz signal generated by the VNA is up-converted to 60 GHz by mixing it with the PLO frequency signal. The 60 GHz signal is transmitted via a directive (horn) antenna with 22.4 dB gain to a human chest at 1 m distance. At the receiver, the signal is mixed with a PLO to be down-converted to 3.5 GHz. The variable attenuator allows obtaining a convenient level at the Low Noise Amplifier (LNA) input. The Band Pass Filters (BPFs) are necessary to remove unwanted signals. The processing part is the same used for the 2.4 GHz system. The result of the heart activity detection is shown in Figure 3 where the minimum variation of the phase is about 40° and the maximum variation is about 50°.

Table 1 60 GHz system blocks and their specifications

Blocks	Specifications
Horn Antennas	3 dB beamwidth: 12°, Gain: 22.4 dB, RF Band: 59-61 GHz
Phase Locked Oscillator	LO frequency: 56.5 GHz, Reference: 70 MHz
Low Noise Amplifier	Band: 2-4 GHz, Gain: min 45 dB, Noise figure: max 1.5 dB
Variable Attenuator	0-70 dB
Up and Down Converter (Mixer 1 and Mixer 2)	IF: 3.5 GHz, PLO: 56.5 GHz, RF: 60 GHz

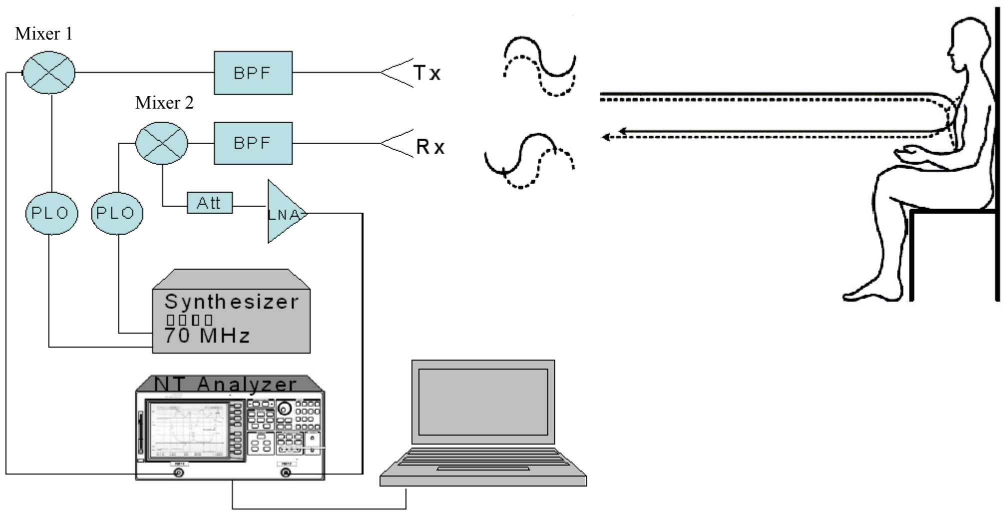

Figure 2 Measurement system operating at 60 GHz

Comparing the results of Figure 1 and Figure 3, the 60 GHz system demonstrates 25 times more sensitivity over the 2.4 GHz system. Moreover, the sharpness and fitness of the signal are improved using the higher frequency.

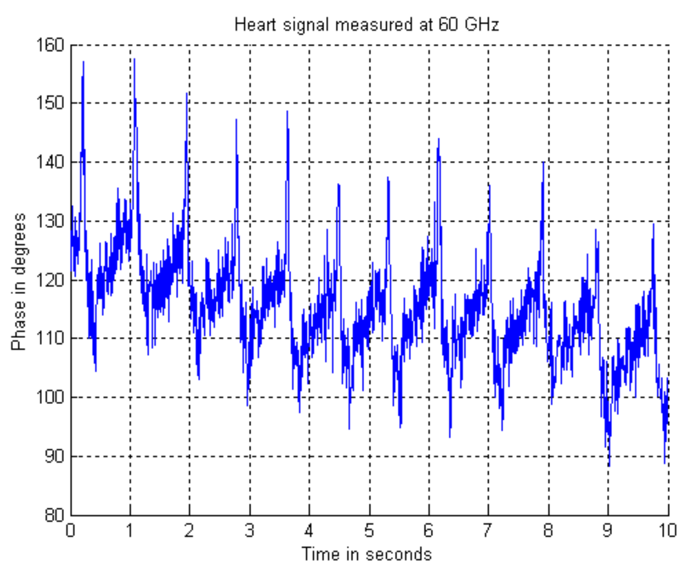

Figure 3 Heart activity detected at 60 GHz and 1 m

Concerning safety, high-frequency emissions such as 60 GHz are absorbed by the moisture in the human body and are thereby prevented from penetrating beyond the outer layers of the skin [8] and can be compared to the exposure to sunlight but at 1/10,000 of the energy.

4. Conclusion

Measurements on two microwave non-contact sensors are performed from a distance of 1 m from the patient. The two systems show good accuracy in detecting the heartbeat signal for an adult (25 years old) with more sensitivity and accuracy when using the 60 GHz approach. The major point in the proposed 2.4 GHz system is that it shows a simple technique to detect heart beating. This scheme is useful for the validation of the measurement set-up before the implementation part of a dedicated system. When compared with the 2.4 GHz system phase, the received signal phase for the 60 GHz frequency is sharper and higher. Equation 1 shows that 1 mm chest displacement gives a phase variation of 5.76° at 2.4 GHz frequency, while the same body displacement gives a phase variation of 144°. This is shown in Figure 1 and Figure 3 where the difference between a local maximum and a local minimum is about 2° at 2.4 GHz and 50° at 60 GHz. Hence, the accuracy in detecting local maxima is directly proportional to the operational frequency.

Our future work will focus on extending the 60 GHz system in order to measure heartbeat under different breathing circumstances. Separating the heart signal from the respiration signal will be easier using the proposed system because of its improved phase sensitivity.

5. Acknowledgments

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