IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331
PP 41-45
www.iosrjournals.org

Wireless Bio- medical Sensor Network for Heartbeat and Respiration Detection

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ABSTRACT: *A wireless bio-medicalr sensor Network was designed to detect a human heartbeat and respiration signals without direct skin contact. In order to design a wireless bio-medical sensor quantitatively, the signal to-noise ratio (SNR) in the baseband output of a sensor should be calculated. Therefore, we analyzed the SNR of the wireless bio- medical sensor, considering the signal power attenuation in a human body and all kinds of noise sources. Especially, we measured a residual phase noise of a typical free-running oscillator and used its value for the SNR analysis. Based on these analysis and the measurement results, a compact, low-cost 2.4 GHz direct conversion bio-medical sensor was designed and implemented in a printed circuit board. The demonstrated sensor consists of two printed antennas, a voltage-controlled oscillator, an I/Q demodulator, and analog circuits. The heartbeat and respiration signals acquired from the I/Q channel of the sensor are applied to the digital signal processing circuit using MATLAB. ECG (electrocardiogram), and reference respiration signals are measured simultaneously to evaluate the performance of the sensor. With an output power of 0dBm and a free running oscillator without a phase locked loop circuits, a detection range of 50 cm was measured. Measurement results show that the heart rate and respiration accuracy was very high.*

Keywords - Biomedical Monitoring, SNR, Wireless Sensor Network,ECG ,Doppler Theory.

I. INTRODUCTION

a wireless bio-radar sensor, fabricated using Doppler theory, has drawn a great deal of attention as a non-contact monitoring system for human healthcare and vital-sign monitoring,such as in cardiopulmonary monitoring for sleep apnea syndrome detection. To measure heartbeat and respiration signals, direct contact measurement using electrodes attached to the skin is generally practiced .A wireless bio-radar sensor needs to be designed in order to measure heartbeat and respiration signals without direct skin contact . A wireless sensor transmits a continuous-wave (CW) signal and demodulates the signal reflected off of a human chestwall. Consistent with Doppler theory, a human chest-wall has a timevarying position with net zero velocity and will reflect a signal with its phase-modulated in proportion to the position of the chest-wall. By demodulating this phase-modulated signal, heart and respiration rates could be obtained. Based on this principle, a wireless bio-radar sensor was first applied to the measurement of respiration rate and the detection of apnea in 1975. Because of the range correlation effect that reduces close-in phase noise, direct-conversion receiver chips with free-running oscillators were able to detect low-frequency heartbeat and respiration without using external crystal and phaselocked loop (PLL) circuits.Also, the null-point issue encountered in general wireless sensors was also avoided by using a quadrature receiver approach .these previous studies mainly focused on receiver architectures and signal processing algorithms, making it difficult to extract the system design parameters directly. In order to simplify the wireless bio-radar sensor design, a signal-to-noise ratio (SNR) analysis is needed, which is commonly used in wireless communication and radar systems. A SNR analysis uses the simple path loss value and various noise effects at the baseband output as design variables. Exact SNR analysis is particularly important when measuring the motion due to heartbeat, since the information is encoded in phase modulations of 0.1 to 10 Hz, where the phase noise is near the peak. To date, there have been few studies about the SNR analysis of a wireless bioradar sensor. the measured flicker noise was considered as a dominant noise sources without exact SNR analysis. Only in was the exact SNR value including the phase noise of the reflected clutter signal analyzed. However, its results did not considered various phase noises due to antenna and mixer leakage signals as noise source. In this paper, therefore, we show the SNR analysis including the path loss in a human body and all kinds of noise powers. Especially, we measured a baseband phase noise of a typical free-running oscillator and used this value for the SNR analysis. Based on these analysis and measurement results, we demonstrate a design example of wireless bio-radar sensor operating at the frequency of the 2.4 GHz Industrial, Scientific, and Medical (ISM) band. We have designed the whole system, from antenna to baseband, to make a compact, low-cost, portable bio-radar sensor.

1.1.Operating Principle Of A Wireless Bio-Radar Sensor

Typical wireless bio-radar sensor architecture is shown in Fig. 1. A sensor is made up of two blocks: the wireless transceiver block, which is used to generate a CW signal and convert the reflected signal to a baseband signal, and the digital signal processing (DSP) block, which is used to determine heart and respiration rates. In the wireless transceiver block, a single oscillator generates both the transmitted RF and local oscillator (LO) signals. When the CW signal is directed at a target, it is reflected and frequency-modulated by the target motion. If the target undergoes a periodic movement $x(t)$ with no net velocity, the Doppler shift of the reflected signal can be described as a phase modulation as shown in (1),

$$\theta(t) = \frac{2f}{c}(2\Pi x(t) = \frac{4\Pi x(t)}{\lambda} \quad (1)$$

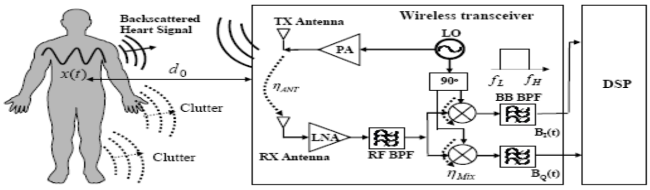

Fig.1 Heartbeat and respiration detection using a wireless bio-radar sensor.

where f is the transmitted frequency in Hz, c is the signal propagation velocity in m/s, and λ is the wavelength of the transmitted signal in meters. The reflected heartbeat and respiration signals are amplified with a low noise amplifier (LNA) and then down-converted to the inphase (I) and quadrature-phase (Q) receiver chains. As shown in Fig. 1, the LO provides two identical frequency signals, one for the transmitter (TX) and the other for the receiver (RX). The LO signal for the receiver is further divided using a 90◦ power splitter to provide two orthonormal baseband outputs. Assuming that the amplitude noise is so small as to be ignored, an LO signal can be expressed as

$$T(t) = \cos(\omega t + \Phi(t)) \quad (2)$$

where ω is the angular frequency, and $\varphi(t)$ is the phase noise of the LO. The LO signal is amplified by a power amplifier (PA), feeds into the TX antenna, and is radiated into the air. Simultaneously, the RX antenna receives backscattered signals from the target. As shown in Fig. 1, the backscattered signals picked up by the RX antenna consist of two components: one is the backscattered signal from the heart and the other is from the stationary human body. The backscattered signal at the RX antenna, $R(t)$, is a time-delayed version of the transmitted signal and can be expressed as

$$R(t)= A_R \cos [\ \omega t - \frac{4\Pi d0}{\lambda} - \frac{4\Pi x(t)}{\lambda} + \Phi(t- \frac{2d0}{c})] \quad (3)$$

where AR is the reflected signal magnitude from the heart, AC is the reflected signal magnitude from the stationary human body, $2d0/c$ and is the round-trip delay between the antenna and human. As the target distance is less than one meter, the channel can be assumed as a free space. Using the Friis electromagnetic wave propagation equation, AR and AC can be given by

$$A_R = \sqrt{\frac{2R_0 P_{rx}\ G_T G_R \lambda^2\ \sigma_h\ L_h}{(4\Pi)^3 {d_0}^4}} \quad (4)$$

respectively, where $R0$ is the input resistance of the bio-radar's receiver, σh and σC are radar cross sections (RCSs), and Lh and LC are reflection losses of the heart and human body, respectively. Now, the received signals are digitized using an analogto- digital converter (ADC). Finally, DSP block are used to separate superimposed heart and respiration signals, to combine quadrature channels, and to determine the heart rate. Generally, the heartbeat is calculated by various detection algorithms, such as zero crossing, autocorrelation,mand Fourier transform.

II. WIRELESS BIO-RADAR SENSOR DESIGN

The wireless bioradar sensor was designed and fabricated. The bio-radar sensor was implemented in a 4-layer printed circuit board. We consider a portable, low-cost bio-radar sensor with a 50 cm detection range. With the previous analysis, the path loss was calculated at 120 dB for a target range of 50 cm, and the signal bandwidth was about 10 Hz. The output power of the designed wireless bio-radar sensor was set to 0dBm for a low-cost design without an additional power amplifier.

Figure 2 shows a photograph of a 2.4 GHz wireless bio-radar sensor for heartbeat and respiration detection. The LO and TX signals are generated by an HMC385LP4 MMIC VCO. The frequency of the VCO is 2.4 GHz ISM band. The power divider divides the power equally to the TX antenna and LO port of the quadrature mixer. As discussed in the previous section, with the same LO sources for transmitting and receiving, the range correlation effect will greatly decrease the phase noise at the baseband to a level that can be ignored.

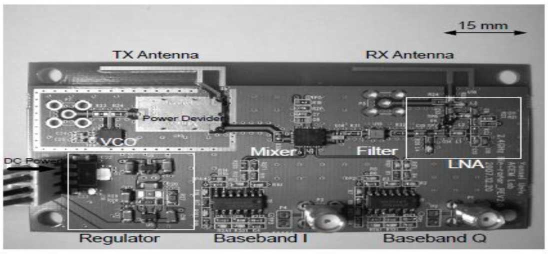

Fig.2. Photograph of a wireless 2.4 GHz bio-radar sensor for heartbeat and respiration detection.

The 2.4 GHz band-pass filter eliminates the spurious interference signal from the RX antenna. The SKY73009 quadrature mixer provides a quadrature output. Down-converted signal from the mixer output goes into the baseband circuits. Heartbeat and respiration signals acquired from the bio-radar sensor are mixed up, so there is a need to separate them. The baseband module is designed to separate the heartbeat and respiration signals acquired from the I/Q channels of the bio-radar sensor and increase the SNR of the signals. The baseband module consists of an offset circuit, a band pass filter circuit, and an amplifier to separate the heartbeat and respiration. The band pass filter for respiration has a frequency bandwidth of 0.05 to 0.5 Hz. The band pass filter for heartbeat has a frequency bandwidth of 1 to 30 Hz. TX and RX dual antennas are used to increase the antenna isolation and then reduce TX leakage. As the measured value of an antenna mutual coupling is about −20 dB, the detection range is to be about 50 cm from our analysis. The PCB size, including dual antennas, is 90mm × 50 mm. The VCO part is isolated using a shield metal to reduce unpredicted interference power on receiver circuits. The regulator provides +5V and +/−3V.

III. MEASUREMENT RESULT

In order to verify the performance of the developed bio-radar sensor, a reference ECG signal and reference respiration signal were measured simultaneously, as shown in Fig. 3 The band-pass filter for the reference 3-lead ECG and reference respiration have frequency bandwidths of 0.5 to 40 Hz and 0.05 to 5 Hz, respectively. Two reference signals, and two heartbeat and respiration signals for each channel of the bio-radar system, making six ports in total, were sampled at a frequency of 480 Hz with 10-bit-resolution A/D using a PIC18F452 (Microchip, USA). The digitized signals were transmitted to a laptop for display.

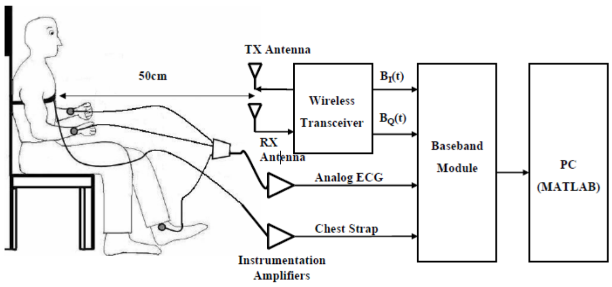

Fig.3.Measurement setup for heartbeat and respiration detection.

Figure 4 shows the results processed during 20 seconds for bioradar signals acquired from the wireless bio radar sensor system at the distance of 50 cm. The bio-radar sensor signal was processed by the 300th FIR low pass filter with a cutoff frequency of 0.5 Hz. After separating heartbeat and respiration, these signals were compared with the reference signal. The bio-radar signal was measured on the frontal side of the subject. Figs. 5(a) and (c) show respiration signals extracted from the I and Q channels, respectively. The extracted respiration signals have close relations to the reference respiration signals. Both the respiration rates are the same, but there exists a phase difference between them. The heartbeat signals extracted from I and Q channel are shown in Figs. 5(b) and (d), respectively. The upper signal and lower signal in each panel show the reference ECG and heartbeat respectively. The heartbeat signals almost coincide with the reference ECG signals, but they are somewhat different in terms of peak to peak interval.

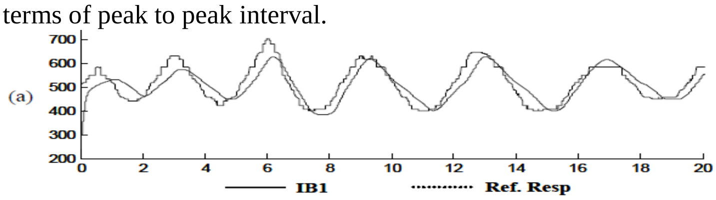

Fig 4.(a). Measurement results of bio-radar signals at the distance of 50 cm respiration signal of I channel.

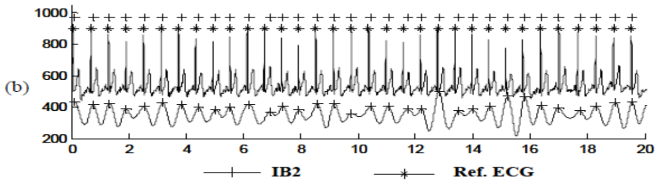

Fig 4 (b).Measurement results of bio-radar signals at the distance of 50 cm heartbeat of I channel.

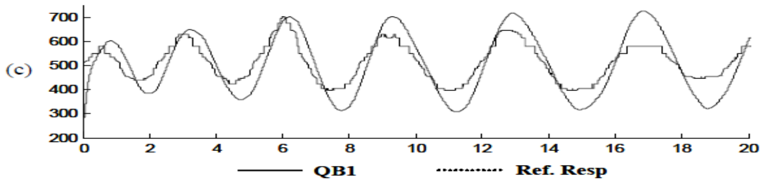

Fig 4.(c).Measurement results of bio-radar signals at the distance of 50 cm respiration signal of Q channel.

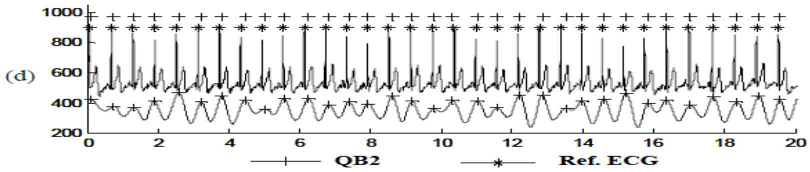

Fig 4.(d). Measurement results of bio-radar signals at the distance of 50 cm heartbeat of Q channel.

IV. CONCLUSION

When system engineers are developing a wireless bio-radar sensor, the SNR is a key design parameter. Accordingly, in this study, a wireless bio-radar sensor was designed using SNR concepts. To calculate the SNR value, the path loss and noise power are necessary. Then, the path loss is derived using the electromagnetic characteristics of human tissues and all kinds of noise sources are calculated. Especially, we measured a residual phase noise of a typical free-running oscillator and used its value for the SNR analysis. Based on these analysis and measurement results, a compact, low-cost 2.4 GHz direct conversion wireless bio-radar sensor was designed and implemented in a 4-layer printed circuit board. The developed sensor consists of two printed antennas, a voltage-controlled oscillator, an I/Q demodulator and analog circuits. With an output power of 0dBm and a free-running oscillator without PLL circuits, a exact heartbeat and respiration signals were measured when using a distance of 50 cm. Measurement results show that the heart rate and respiration accuracy was found to be very high. We verified that the wireless bio-radar sensor could detect heartbeat and respiration well without contact and our SNR analysis could be effective tool to design a wireless bio-radar sensor.

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