UHF Measurement of Breathing and Heartbeat at a Distance

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***Abstract* — The detection of breathing and heartbeat from a distance is important for medical triage and mass casualty events as well as routine monitoring of higher-risk patients. Typical approaches include wiring up patients to devices and wearable devices, but remote detection and monitoring is both easier on the patient and easier to administer. Monitoring at low frequencies means that there is less patient risk as well as extended range and reduced power.**

In this paper we look at the measurement of breathing and heartbeat of human subjects at UHF frequencies. We characterize the system design and capabilities as well as the algorithmic approach to extracting the signal. We measure biometric ground truth using heartbeat sensors, respiration monitors, and accelerometers. We do accurately measure breathing, and can measure heartbeat when the subject is holding his breath, but have not yet separated the heartbeat from breathing when both are being done simultaneously.

***Index Terms* — Radar, heartbeat, breathing, UHF.**

I. Introduction

The treatment for heart disease, lung disorders, and asthma accounts for three-fourths of total US healthcare costs and afflicts more than 100 million Americans [1]. With an aging population suffering from chronic illnesses, health monitoring is becoming increasingly important, especially monitoring heart beat and respiration rate. Doppler radar has shown the ability to detect and monitor as respiration and heart beat as a remote and noninvasive method. Body movements caused by respiratory and circulatory contraction and expansion produce a Doppler shift which can be measured by a radar signal reflected from the body. The sensor is not required to touch the patient's body, and minimal training is necessary, so this approach is very attractive for in home care and monitoring [2].

There are many potential techniques to monitor respiration and/or heartbeat. Single photon emission tomography is good for mapping the autonomic nervous system, but is impractical for monitoring due to the need for large-scale equipment [3]. Using continuous electrocardiography with conventional electrodes, the rhythmic components of heart-rate variability (HRV) can be assessed [4], [5]. However, long-term electrocardiographic monitoring using electrodes places a heavy burden on the monitored individuals. Doppler radar, operating at microwave frequencies in the range of 1–10 GHz, has long been suggested as a means to accomplish this [6]–[9]. More recently, RF technology has been applied to implement such devices [10]–[14], and generalized to sensing of multiple subjects [15]–[17]. A discourse on the subject including physiological background can be found in [18].

Many of the studies to date have been done in the form of laboratory experiments under ideal conditions, so there is no certainty that reliable instruments can be produced. Some of the potential problems include the effects of background scatter, the motion of the subject, and interference between the respiration and heartbeat signals. Background scatter from the ambient surroundings as well as from the subject's body [19] add to the clutter line, while the motion of the subject and other objects will add to the measured Doppler signals. There is also the problem of respiration harmonics falling close to the heartbeat frequency so as to make reliable heart-rate estimation difficult [20].

II. Phenomenology

The equation for computing the non-relativistic Doppler frequency shift, F_d, of a simple point scatterer moving with speed υ with respect to a stationary transmitter is

$$F_d = F_t \frac{2v}{c} \cos\theta \cos\phi$$

where F_t is the frequency of the transmitted signal, θ is the angle between the subject motion and the beam of the radar in the ground plane, ϕ is the elevation angle between the subject and the radar beam, and c is the speed of light. For complex objects, such as walking humans, the velocity of each body part varies over time. Additionally, the radar cross-section of various body parts is a function of aspect angle and frequency.

Using a Fast Fourier Transform (FFT), the frequency bin span of a radar system operating at a sample rate of 1 KHz for 200 ms is 5 Hz. At UHF, body parts moving less than 1 m/s will image in the zero-Hertz (DC) bin. Some information may be extracted, however, by analyzing the phase of the DC bin. As an example, a displacement of 1 mm at 400 MHz results in a phase change of 0.16 degrees. Ka-band frequencies, with higher Doppler shifts,have the potential to measure very fine detail within the dismount Doppler spectrum [21].

III. Instrumentation

A human subject use protocol was developed to satisfy safety and privacy requirements for collecting RF

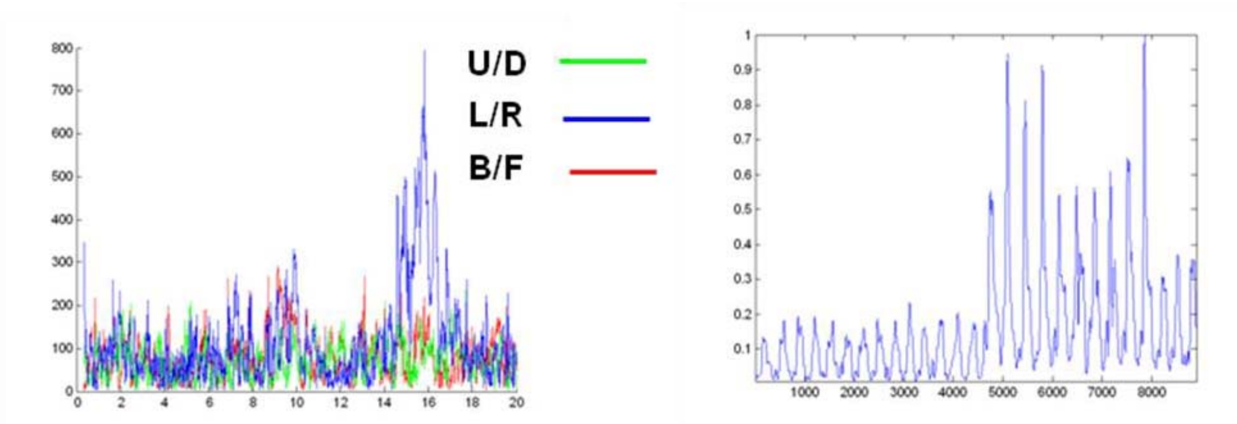

Figure 1. Accelerometer measurements and microphone measurements of a subject in the chamber. The U/D line is the up and down motion, while L/R is left and right motion, and B/F is the back and forward motion. The change in the microphone data is the subject going from breathing to counting aloud.

measurements of humans. To provide corroborating data for understanding the signatures observed in the radar data, biometric measurements were collected. Respiration was monitored using a head-mounted microphone. The RMS voltage from the microphone measured occurrences of inhalation and exhalation. Speech was evident as a higher voltage output from the microphone. Heartbeats were monitored using a Polar® T31 chest strap, which emitted a pulse whenever a heartbeat occurred. Accelerations of the body were monitored using a 3-axis accelerometer, which was worn around the waist. The accelerometer data provided measurements of motion in the forward, backward, side-to-side, and vertical directions. The microphone and accelerometer data is shown in Figure 1. The biometric channels were sampled at 1 KHz by a Graphtec GL500AMS data logger. Video frames of the measurement were collected at 30 Hz using a high-definition video camera.

A UHF radar was used in an anechoic chamber to collect measurements of heartbeat and breathing. Subjects were also asked to sit or stand to collect micro-Doppler measurements of breathing and heartbeat. The transmit antenna of the UHF radar, a TACO Yagi Y55, was located 11.3 meters from the subjecct at the apex of the chamber. The receiver antenna, an ETS-Lindgren quad ridged antenna model 3164-03, was located 4.3 meters from the subject. The receiver was offset from the line-of-sight to the transmitter by 12-degrees. The block diagram of the radar is shown in Figure 2.

The transmitted waveform was generated by a Direct Digital Synthesizer (DDS). The DDS was programmed with a swept CW waveform that began at 350 MHz and ended at 425 MHz. The external clock for the A/D samples was derived from the DDS clock and operated at 6.25 MHz. The waveform was sampled at 6250 frequencies during the sweep. Various band-pass filters were added to the circuitry to remove harmonics and spurious signals. Coherent phase detection measured both

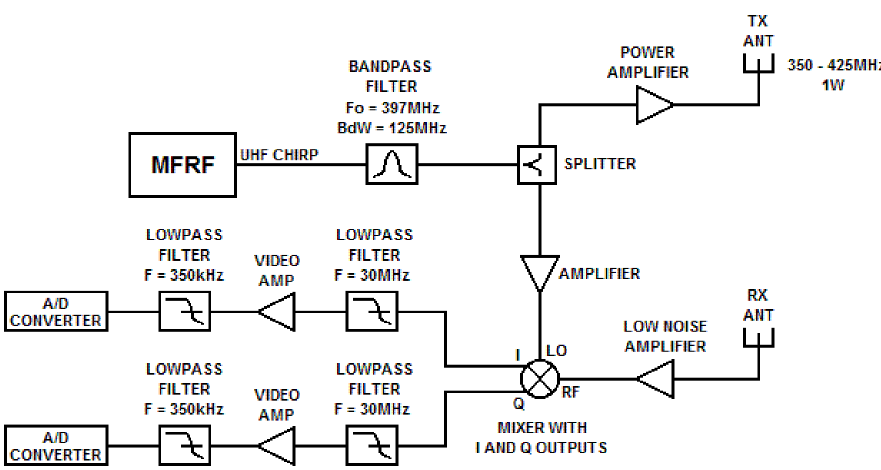

Figure 2. RF circuitry used to measure micro-Doppler at UHF.

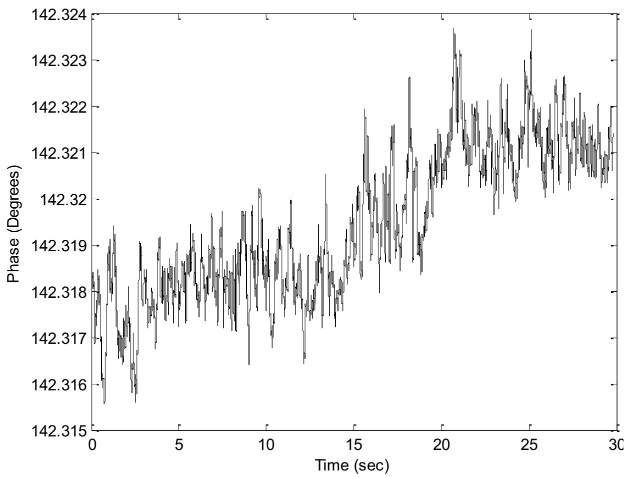

Figure 3. Background phase measurement at UHF

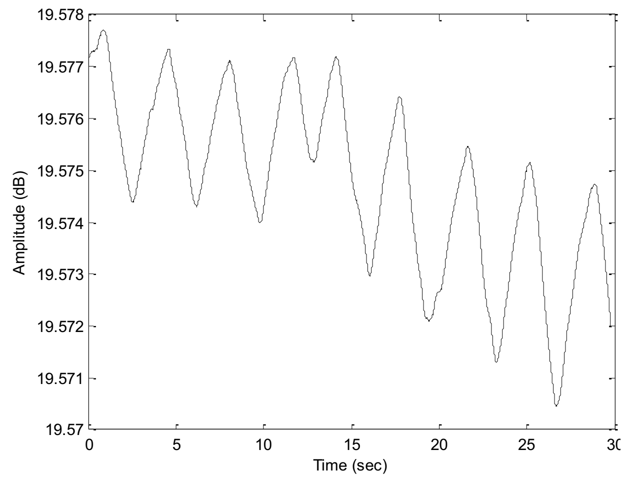

Figure 4. Amplitude measurement of breathing

in-phase and quadrature-phase components of the received signal. The background phase of the system is shown in Figure 3.

III. MEASUREMENTS

Measurements of human micro-Doppler at UHF were performed to determine whether the breathing and heartbeat of a human subject could be extracted at UHF. In the first experiment the subject breathed normally and the results are shown in Figure 4. Having successfully detected breathing, the more difficult heartbeat measurement was done with the subject supine and instructed to hold their breath several seconds after the

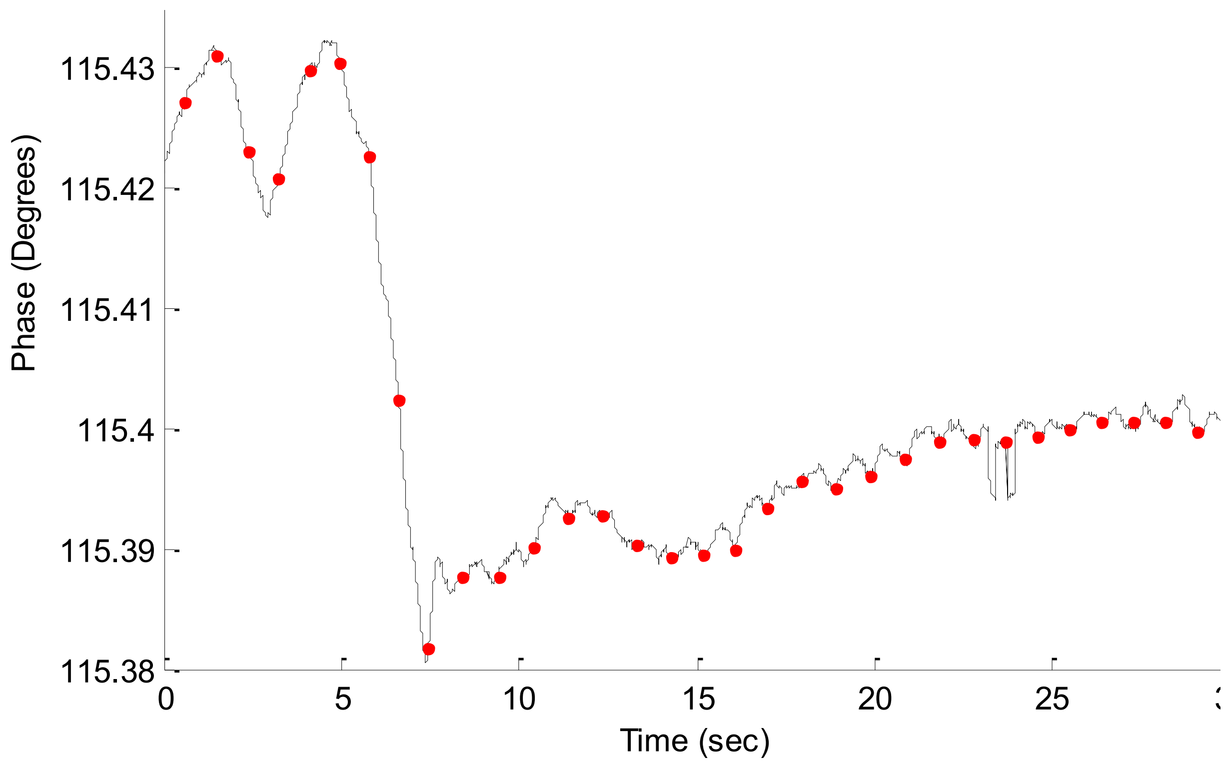

Figure 5. Phase modulation of shallow breathing and heartbeat at UHF. Circles indicate heartbeats as measured by the chest monitor. The subject begins the breath hold at seven seconds into the experiment.

Heart beat monitor

data collection began. Figure 5 shows the phase of the DC bin of the spectrogram during this experiment and the moment at which the subject began the breath hold can easily be discerned. The phase modulations that occur afterward are highly correlated with the heartbeat as measured by the chest monitor. The order-of-magnitude of the phase variation was less than 0.01 degrees.

IV. Conclusions

In this paper we measured breathing and heartbeat of human subjects at UHF frequencies. We developed a phase-stable radar whose the system design provides the capability of measuring breathing and heartbeat. We did not separate the two measurements, but hope to do so in the near future. We developed the algorithmic approach for extracting the signal from the zero-hertz Doppler bin using either the amplitude or phase. We measure biometric ground truth using heartbeat sensors, respiration monitors, and accelerometers, and find good agreement.

The measurement of breathing and heartbeat at UHF allows for the potential development of through-the-wall measurement of breathing for finding humans trapped in rubble during a disaster.

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