

Clutter Rejection using A 4-to-8 GHz Harmonic Radar System with Nonlinear Tags for Contactless Respiration Monitoring

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Abstract— This paper presents a portable harmonic radar system operating at 4 and 8 GHz, paired with nonlinear passive tags, for contactless respiration monitoring in biomedical applications. The system features a lightweight, flexible tag embedded with a Schottky diode, generating harmonic frequencies for robust detection. Experimental validation was conducted using a UFI PneumoTrace II respiration belt as ground truth, with the nonlinear tag attached to the subject's chest and the setup surrounded by clutter sources with moving corner reflectors at a distance of 1.2 m. This study introduces corner reflectors to simulate clutters with high radar cross-section (RCS), providing a controlled comparison. Results demonstrate the system's ability to suppress high RCS motion artifacts from nearby clutter sources.

I. INTRODUCTION

Accurate and non-invasive biomedical monitoring systems play a significant role in advancing continuous health monitoring. Traditional contact-based systems, such as wearable sensors, often face limitations in user comfort, hygiene, and long-term usability, making them less suitable for continuous monitoring [1]. These challenges have driven the advancement of radar-based technologies, which enable contactless monitoring of physiological activities such as respiration and heart rate [2], [3].

Harmonic radar systems paired with nonlinear tags provide unique advantages in clutter rejection and sensitivity, making them well-suited for biomedical applications [4]. These systems operate by transmitting a fundamental frequency and receiving a second harmonic generated by the nonlinear tag. The Schottky diode embedded in the tag enables this harmonic generation, allowing the radar to isolate the tag's response from environmental clutter. This frequency-selective mechanism has been widely recognized as a robust solution for non-contact physiological detection for search and rescue [5].

Previous research has demonstrated the versatility of radar-based systems in various contexts. For example, Doppler radar systems have been employed for vital sign monitoring with flexible antenna designs that facilitate non-contact detection [2]. Similarly, FMCW radar has been used to detect vital signs in multi-target scenarios, overcoming challenges such as random body movement using advanced filtering techniques [3, 6]. However, these systems can struggle with random movement environments and require active tag operations.

This paper presents a harmonic radar system design optimized for high linearity and evaluates its performance using actuators mounted with corner reflectors as clutter

sources. Unlike previous studies involving multi-person scenarios, where human subjects introduced significant motion clutter [7], corner reflectors provide a higher radar cross-section (RCS) and a well-defined, reproducible clutter profile. These characteristics make them ideal for systematically assessing the system's enhanced clutter rejection capabilities. This study demonstrates the system's robustness in rejecting interference, highlighting its potential for real-world biomedical applications

II. PORTABLE HARMONIC SYSTEM

The harmonic radar system diagram and test boards, as shown in Figure 1 (a) and (b), is designed to ensure high linearity and minimize harmonic leakage, accurately isolating the second harmonic frequency generated by the nonlinear tag. The system architecture consists of three main components: the transmit (TX) chain, the local oscillator (LO) chain, and the receive (RX) chain. Each is optimized by carefully placing filters and amplifiers to maintain system linearity.

The TX chain generates and transmits the 4 GHz fundamental signal to excite the nonlinear tag. The signal originates from a voltage-controlled oscillator (VCO) and is split into two paths by a power splitter: one directed to the TX chain and the other to the LO chain. In the TX chain, the 4 GHz signal is amplified using an RF amplifier, and a bandpass filter (BPF) is placed after the amplifier to suppress unwanted harmonic frequencies. This configuration ensures that only the fundamental frequency is transmitted, reducing interference and maintaining system linearity.

The LO chain provides the 8 GHz signal needed for down-conversion in the RX chain. The 4 GHz signal from the power splitter passes through a frequency multiplier to generate the second harmonic. A BPF then filters out any residual 4 GHz signal to prevent interference in the RX chain.

The RX chain captures and processes the 8 GHz harmonic signal reflected from the nonlinear tag. The chain employs high-pass filters (HPFs) and RF amplifiers to isolate and amplify the harmonic signal while rejecting the fundamental frequency. The first HPF is placed after the receiving antenna to block the 4 GHz fundamental frequency. Three RF amplifiers provide a total gain of 48 dB, with additional HPFs placed after the first and second amplifiers to remove any fundamental frequency components generated during amplification. A final HPF, positioned before the mixer, ensures that only the harmonic signal is processed.

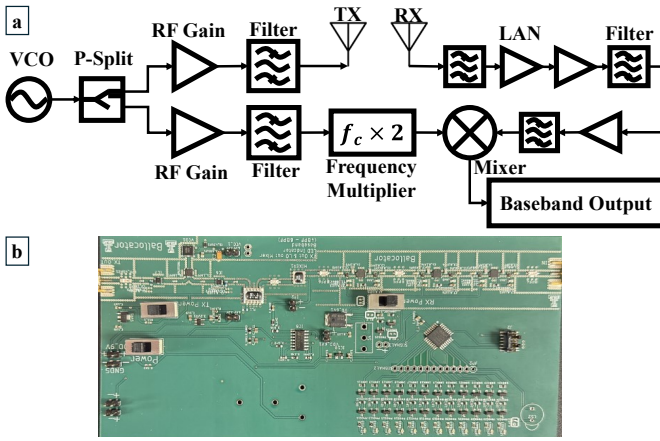


Figure 1. Harmonic system (a) diagram and (b) system test board.

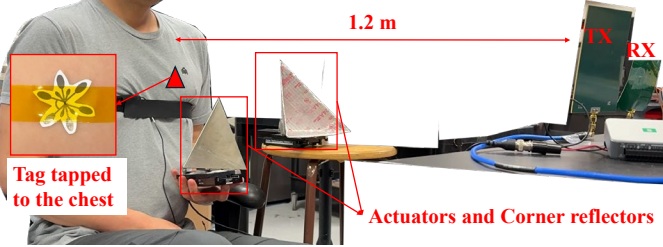


Figure 2. Experiment setup.

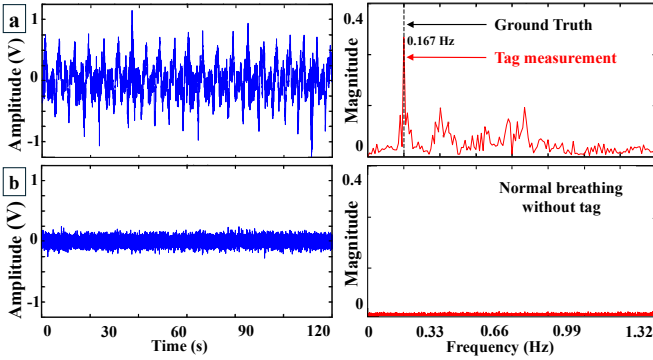


Figure 3. Time and frequency domain plots of (a) tagged respiration measurement compared to ground truth and (b) un-tagged measurement.

III. EXPERIMENT RESULTS AND VALIDATION

The experimental setup, as shown in Figure 2, was designed to validate the accuracy and robustness of the harmonic radar system in detecting respiratory activity. The choice of corner reflectors was motivated by their ability to reflect radar signals efficiently, creating a high RCS that challenges the radar's clutter rejection performance. Compared to human-induced clutter from previous studies, which is less predictable and variable in RCS [7], the use of corner reflectors enables precise and repeatable testing. A UFI PnuemoTrace II 1132 piezo-electric respiration transducer was strapped to the test subject's chest as the ground truth measurement. A nonlinear tag was securely taped to the subject's chest and covered by a single layer of clothing to simulate realistic conditions. The distance between the transmit (TX) and receive (RX) antennas and the subject's chest was maintained at 1.2 meters.

To simulate potential clutter, actuators mounted with corner reflectors were introduced. One actuator was held by the

subject in front of the chest area. Care was taken to ensure that the corner reflectors did not block the line of sight (LOS) between the tag and the antennas, while another was placed on a chair at chest height beside the subject. The corner reflectors were chosen for their high RCS, which provides a well-defined and consistent clutter source. Unlike human-induced clutter, corner reflectors offer a controlled and reproducible RCS profile, allowing for systematic evaluation of the system's clutter rejection capabilities. Both actuators were programmed to swing with an amplitude of 5 mm at a frequency of 1 Hz, introducing dynamic clutter near the monitored subject. Data acquisition was performed using a National Instruments NI USB-6003 data acquisition system.

The data collected, as shown in Figure 3, demonstrated the system's ability to detect respiratory activity accurately while rejecting interference from nearby clutter. The harmonic radar system captured the nonlinear tag's signal and agreed with the ground truth respiration data obtained from the PnuemoTrace II transducer. Over a two-minute monitoring period, the system recorded 20 breaths, corresponding to a respiration rate of 0.167 Hz. Importantly, no motion artifacts from the actuators, either held by the subject or placed on the chair, were detected in the captured data. This result indicates effective suppression of clutter from moving reflectors.

IV. CONCLUSION

This study demonstrated the effectiveness of a harmonic radar system operating at 4 GHz, paired with nonlinear passive tags, for accurate contactless respiration monitoring in cluttered environments. By introducing corner reflectors as high RCS clutter sources, the system's ability to reject interference was systematically evaluated, offering a controlled comparison to human-induced clutter in previous studies. The system accurately captured respiratory activity, with results matching the ground truth provided by a respiration belt, and effectively suppressed motion artifacts from nearby moving reflectors.

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