A Portable Doppler/FSK/FMCW Multi-mode Radar With Analog DC Offset Cancellation for Biomedical Applications

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***Abstract*—This paper presents an integrated portable multi-mode radar system incorporating Doppler, frequency-shift keying (FSK), and frequency-modulated continuous-wave (FMCW) modes with an analog DC offset baseband cancellation circuit. The proposed radar system can be used for various biomedical applications such as non-contact vital signs monitoring, fall detection, and human tracking. A common problem of biomedical radar sensors is the DC offset presented at the output of the mixer caused by hardware imperfection and reflections from nearby stationary objects. This leads to signal distortion, baseband amplifier saturation, and dynamic range reduction. Therefore, an analog DC offset cancellation circuit is integrated to automatically and continuously remove the DC offset before baseband amplification. Experiment results of different modes are reported to demonstrate the multi-functionality of the proposed radar.**

I. Introduction

Doppler radar [1], frequency-shift keying (FSK) radar [2], and frequency-modulated continuous-wave (FMCW) radar [3] have been demonstrated for various biomedical applications including contactless vital signs monitoring, fall detection, and movement tracking. In this work, a fully integrated radar sensor incorporating Doppler, FSK and FMCW modes and a DC offset cancellation unit were fabricated and successfully tested. The switch among different functions is easily controlled by three jumpers on the board. Compared with the independent radar systems, the integrated radar sensor enables multiple functions in one block with low cost, light weight, compact size, and easy configuration. Lab experiments demonstrated that the integrated multi-mode sensor works properly under different mode configurations to meet the demand of user-centered sensing and tracking in the internet of things (IoT) era.

II. Multi-mode Radar Design

Fig. 1 details the block diagram of the proposed portable multi-mode radar system. It is mainly composed of three parts, i.e., waveform generation circuit, radio frequency (RF) front-end, and baseband amplification circuit with analog DC offset cancellation unit. The generation of three different modes are realized by sending corresponding control signal to the free-running voltage-controlled oscillator (VCO). In the Doppler mode, a single frequency is generated by controlling the VCO with a constant DC voltage. This DC voltage is made tunable through a potentiometer connected between 5 V and ground to tune the transmit frequency. In the FSK mode, an operational-amplifier-based circuit is employed to generate square wave signal, which switches the VCO between two carrier frequencies. Sawtooth wave is used instead in the FMCW configuration to generate linear frequency chirps. The mode of operation can be changed by disconnecting the current control signal and connecting the desired control signal via short cap jumper, as shown in the photograph of the fabricated multi-mode radar in Fig. 2. These three radar modes share most of the RF components and signal paths. Therefore, system cost and complexity are significantly reduced.

In the baseband amplification circuit, an analog DC offset cancellation design is implemented to automatically remove the DC offset and increase system dynamic range. Compared with AC-coupling technique, this method has faster settling time and solves the problem of low-frequency distortion. It requires less manual work than manual calibration and does not need software configuration compared with software-related solutions [4]. The design details and working theory are explained in [5].

The authors would like to acknowledge grant support from National Science Foundation (NSF) ECCS-1254838, CNS-1718483 and ECCS-1808613.

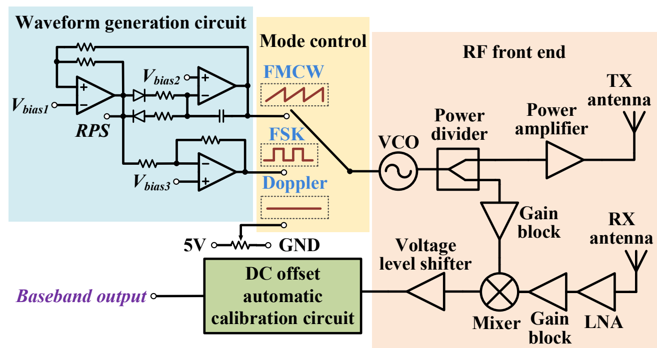


Fig. 1. Block diagram of the proposed multi-mode radar system.

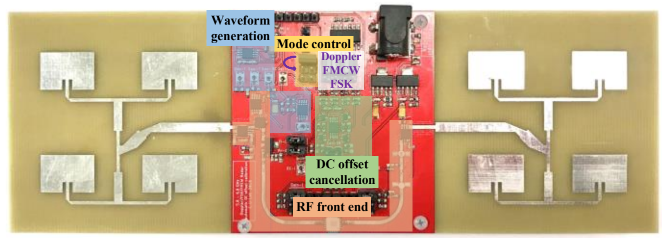
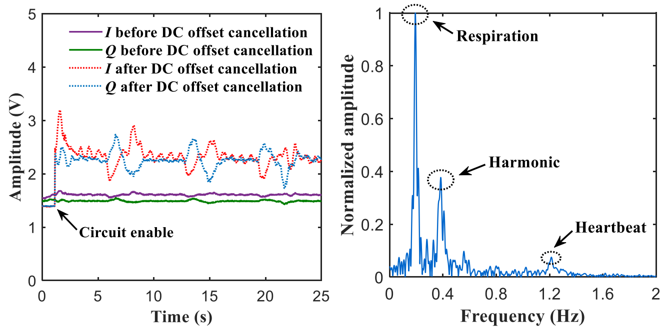
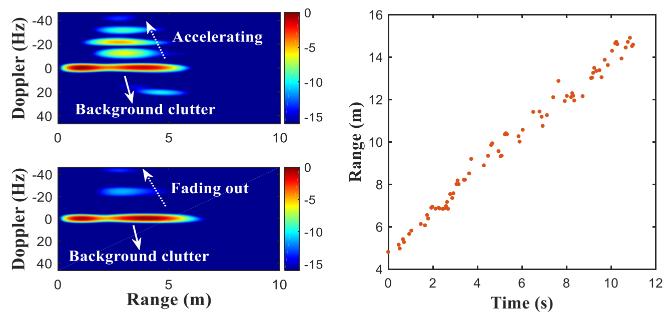


Fig. 2. Photograph of the fabricated multi-mode radar.



(a) (b)

Fig. 3 (a) Recorded vital signs monitoring results before and after DC offset cancellation. (b) Spectrum of the baseband signal after the DC offset cancellation circuit was enabled.



(a) (b)

Fig. 4 (a) Range-Doppler images of acceleration phase and fading phase during falling toward radar incident in FMCW mode. (b) Range tracking of a human subject using FSK mode.

III. Experiments

A. Vital signs detection

The vital signs detection theory using Doppler radar has been detailed in [1]. In this experiment, Doppler mode with 5.8-GHz transmit frequency was set up, measurement was performed when a human subject seated 1 m in front of the radar in a lab environment. To eliminate null detection point problem, both in-phase/quadrature (*I/Q*) channel outputs were recorded and combined to recover respiration and heartrate. NI USB-6009 with sampling rate of 160 Hz was used for data acquisition.

Fig. 3 (a) plots the *I/Q* channel outputs before and after the DC offset cancellation circuit. As can be seen, the DC level of the original *I/Q* signal are around 1.5 V and 1.6 V. At around 0.5 s, the DC offset cancellation circuit was enabled and the outputs jumped to the middle voltage of the supply rails (ground and 5 V) almost instantly taking advantage of the fast charging circuit in the design [5]. In this way, *I/Q* signals will stay at the optimal DC level independent of the nearby clutter reflections so that the baseband amplifier operates with the highest dynamic range. As shown in Fig. 3 (b), both the respiration and heartrate were successfully detected in the baseband spectrum. Note that the harmonic frequency is caused by the non-linear property of cosine transfer function [1].

B. Fall detection

Fall incident was mimicked to show the capability of the FMCW mode in fall detection. The operation center frequency was at 5.8 GHz with 250 MHz bandwidth. The sawtooth generation circuit simultaneously synthesized a 417 Hz reference pulse sequence (RPS) which was synced with the sawtooth control signal. The RPS along with the beat signal were sent to the audio card of a laptop and sampled with 192 KHz frequency. A human subject standing 3.5 m away fell toward the radar. During the event, strong and sudden Doppler frequency change with decreasing range should be observed due to the acceleration of human body toward radar, as presented in the upper plot in Fig. 4 (a). As the subject kept falling and eventually hit ground, the range-Doppler signature of the human subject should experience a fading phase and then disappear on the image. One frame of the fading period is shown in the lower image of Fig. 4 (a) to demonstrate the vanishing range-Doppler signature.

C. Human tracking

The functionality of the FSK operation was tested in an interior corridor by tracking the movement of a walking human subject. The two transmit frequencies were set as 5.68 GHz and 5.69 GHz with a switching frequency of 550 Hz, resulting in a maximum unambiguous detection range of 15 m [2]. To avoid near-field issues, the human subject started the movement 5 m away from the radar with a normal walking speed and stopped at around 15 m. The square wave control signal and baseband output were recorded simultaneously using NI USB-6009 with 6 KHz sampling frequency. Explanation of FSK radar human tracking theory can be found in [2]. Human tracking measurement result plotted in Fig. 4 (b) has shown good performance which verifies the FSK mode operation.

IV. Conclusion

The design of an integrated Doppler/FSK/FMCW multi-mode radar sensor with DC offset automatic cancellation circuit is presented. Functionality of the three operational modes and the performance of DC offset cancellation have been demonstrated through vital signs monitoring, fall detection, and human tracking experiments. The portable multi-mode radar has great potential to serve as an important IoT tool for various biomedical applications.

References

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