A Portable 24-GHz FMCW Radar based on Six-Port for Short-Range Human Tracking

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***Abstract* — A 24-GHz portable FMCW radar for short-range human tracking is designed, fabricated, and tested. The complete radar system weights 17.3 grams and has a dimension of 65mm×60mm×25mm. It has an on-board chirp generator, which generates a 45.7 Hz sawtooth signal to control the VCO. A 1.8-GHz bandwidth ranging from 22.8 GHz to 24.6 GHz is transmitted. A pair of Vivaldi antennas with a bandwidth of 3.8 GHz, ranging from 22.5 GHz to 26.3 GHz, are implemented on the same board with the RF transceiver. A six-port structure is employed to down-convert the RF signal to baseband. Measurement result has validated its promising ability to for short-range human tracking.**

***Index Terms* — FMCW radar, short-range, human tracking, six-port, Vivaldi antenna.**

I. Introduction

Radar systems have various applications in bio-medical area. There have been many researches focusing on human tracking [1], gesture recognition [2], and vital sign detection [3][4], etc. Among various types of radars, the frequency modulated continuous wave (FMCW) radar can provide accurate range information of the targets, which makes it very useful for short-range human tracking applications. Compared with conventional human localization and surveillance methods such as GPS and cameras, FMCW radar has its unique advantages including accurate measurement of absolute distance and see-through-obstacle capability.

Some of the key requirements for a FMCW radar in short-range human tracking application are low profile and cost effective. A small and light weighted radar device makes it much easier to be mounted on the wall or integrated with other devices such as Wi-Fi routers and smart phones. Moreover, with a low cost, multiple radars can be deployed to improve coverage and establish radar sensor network [5].

In this paper, a 24-GHz portable FMCW radar is designed, fabricated, and tested. To minimize the cost and power consumption, the radio frequency front-end and the antennas are integrated on a single flexible printed circuit board (PCB), and very few commercial RF components are used. This radar system is highly integrated with a VCO, a pair of LNAs, a six-port [6] structure, two wideband antennas, analog chirp signal generator and baseband processing unit. The net weight and the size of the radar system are 17.3 grams and 65mm×60mm×25mm, respectively.

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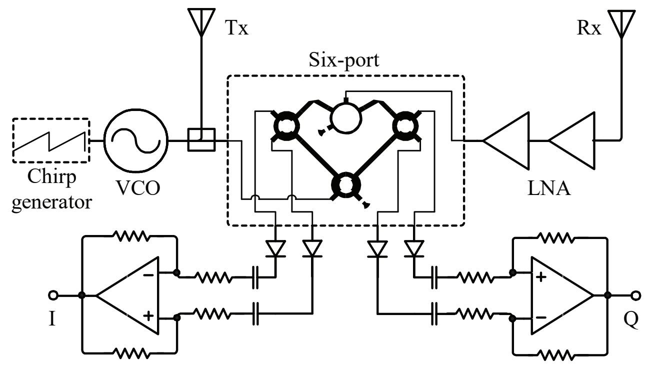


Fig. 1. Block diagram of the proposed 24-GHz FMCW radar.

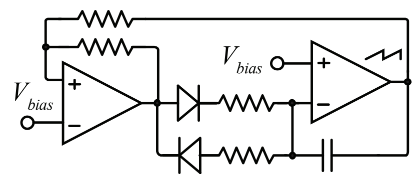


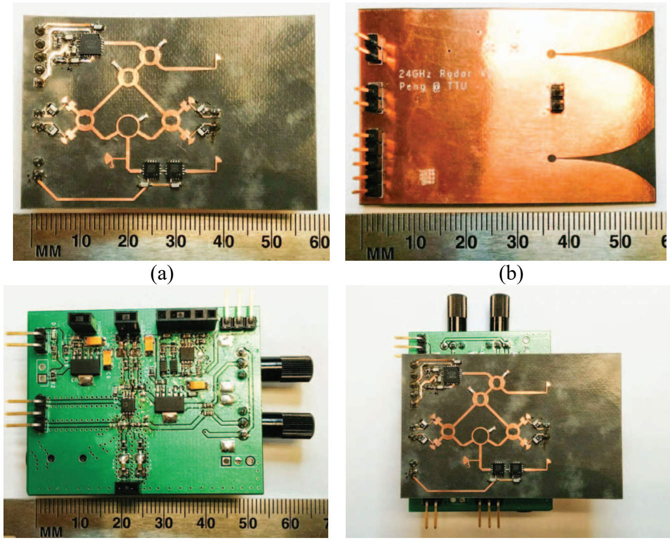
Fig. 2. Schematic of the on-board analog chirp generator.

II. Design Principle

Figure 1 shows the schematic of the proposed portable FMCW radar. The on-board chirp signal generator generates a 45.7 Hz sawtooth voltage, which control the VCO to sweep from 22.8 GHz to 24.6 GHz with a bandwidth of 1.8 GHz. The VCO output is divided into two parts equally. One part is transmitted through antenna, and the other part acts as the LO to drive the Six-port mixer. In the receiver channel, the signal is amplified by two-stage LNAs and then enters the six-port mixer. The outputs of the six-port are differential quadrature signals, which are amplified by two differential amplifiers.

The on-board chirp generator is designed based on two operational amplifiers. The left amplifier works as a comparator while the right one works as an integrator. The charge and discharge currents of the capacitor go through two different resistors because of the two diodes. Thus the rising time and falling time of the chirp signal are different, achieving a sawtooth signal. V_{bias} controls the DC bias of the chirp signal. The chirp frequency is designed to be 45.7 Hz.

Six-port is a simple structure to down-convert RF signal into baseband, avoiding the use of expensive integrated mixer chips [6]. The six-port structure used in this design consists of three quadrature couplers and one rat-race coupler, as shown in Fig. 1. This structure is design and fabricated on Rogers RT/duroid 5880 substrate with a thickness of 0.254mm.



(a) (b) (c) (d)

Fig. 4. Photos of the portable FMCW radar. (a) Front of the RF board. (b) Back of the RF board. (c) Baseband board. (d) Photo of the entire radar system.

Four Schottky diodes are used to mix the received signals with LO signals. Since the radar is working at 24 GHz, the non-linear effect will be minimized if the parasitic capacitor of the Schottky diode is not small enough. In this design, Skyworks SMS7621-060 diodes with 0.18pF parasitic capacitance are used.

The outputs of the six-port are differential quadrature signals. These quadrature signals are amplified by differential amplifiers and then used for further signal processing.

Since the transmitting bandwidth of this portable radar is about 1.8 GHz, wideband antennas are required. Vivaldi antenna, which has very wide bandwidth and moderate gain, is used in this radar system. Another reason to use this antenna is that it can be easily fabricated on the PCB used. Simulation shows a frequency band from 22.5 GHz to 26.3 GHz. The gain of the antenna is about 9.3 dB at 24 GHz.

III. Prototype and Experiment

The prototype radar consists of two boards stacked together: an RF board on Rogers RT/duroid 5880 substrate and a baseband board on FR4 substrate. Figs. 4(a) and 4(b) show the front and the back of the RF board, respectively. The RF board includes a VCO, two LNAs and the six-port structure. Fig. 4(c) is the photo of the baseband board. Fig. 4(d) is the photo of the whole portable FMCW radar with RF board and baseband board being stacked together.

To verify the performance of the portable FMCW radar, experiments were performed. During the experiment, a human subject was asked to walk towards and/or away from the radar with different speed. Fig. 5 shows the range history. The x axis represents the distance between the human subject and the radar, and the y axis is the time. The bright trace in the figure represents the position of the human subject at different times.

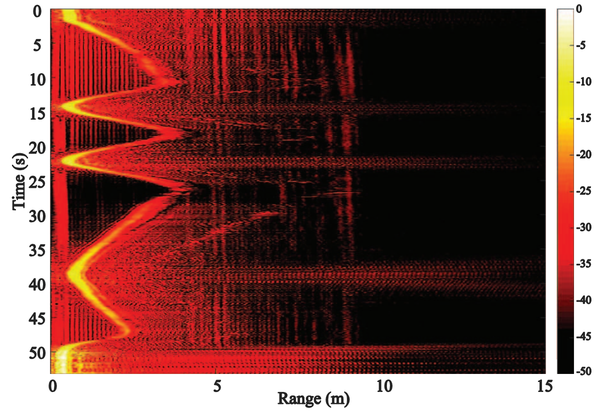


Fig. 5. Human tracking experiment result using the developed radar.

The trace of the subject's movement is clearly shown in Fig. 5, and the slope of the trace indicates the varying walking speed.

IV. Conclusion

A 24-GHz portable FMCW radar for human tracking is designed and tested. This radar is highly integrated with a VCO, a pair of LNAs, a six-port structure, two wideband Vivaldi antennas, an analog chirp signal generator and a baseband processing unit. In order to minimize the cost and power consumption of the system, the RF front-end and antennas are integrated on a single PCB, and very few commercial RF components are used. Experiment using this portable FMCW radar has demonstrated its ability in short-range human tracking.

References

[1] G. Wang, C. Gu, T. Inoue, and C. Li, "A Hybrid FMCW-Interferometry Radar for Indoor Precise Positioning and Versatile Life Activity Monitoring," *IEEE Trans. Microw. Theory Techn.*, vol. 62, no. 11. pp. 2812–2822, November 2014.

[2] Q. Wan, Y. Li, C. Li, and R. Pal, "Gesture recognition for smart home applications using portable radar sensors," *Engineering in Medicine and Biology Society (EMBC), 2014 36th Annual International Conference of the IEEE*. pp. 6414–6417, August 2014.

[3] F.-K. Wang, T.-S. Horng, K.-C. Peng, J.-K. Jau, J.-Y. Li, and C.-C. Chen, "Single-antenna Doppler radars using self and mutual injection locking for vital sign detection with random body movement cancellation," *IEEE Trans. Microw. Theory Techn.*, vol. 59, no. 12, pp. 3577–3587, December 2011.

[4] M. Mercuri, P. J. Soh, G. Pandey, P. Karsmakers, G. Vandenbosch, P. Leroux, and D. Schreurs, "Analysis of an indoor biomedical radar-based system for health monitoring," *IEEE Trans. Microw. Theory Techn.*, vol. 61, no. 5, pp. 2061–2068, May 2013.

[5] Y.-S. Su, C.-C. Chang, J.-J. Guo, and S.-F. Chang, "2-D wireless human subjects positioning system based on respiration detections," *Microwave Symposium Digest (MTT), 2012 IEEE MTT-S International*. pp. 1–3, June 2012.

[6] S. O. Tatu and K. Wu, "Six-port technology and applications," *Telecommunication in Modern Satellite, Cable and Broadcasting Services (TELSIKS), 2013 11th International Conference on*, vol. 01, pp. 239–248, October 2013.