Compact 24-GHz Doppler Radar Module for Non-Contact Human Vital-Sign Detection

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***Abstract* – A compact 24-GHz Doppler radar module is developed in this paper for non-contact human vital-sign detection. The 24-GHz radar transceiver chip, transmitting and receiving antennas, baseband circuits, microcontroller, and Bluetooth transmission module have been integrated and implemented on a printed circuit board. For a measurement range of 1.5 m, the developed radar module can successfully detect the respiration and heartbeat of a human adult.**

***Index Terms* —Non-contact vital-sign sensor, 24 GHz radar, respiration and heart beat detection, Doppler radar**

1. Introduction

Microwave Doppler radars with different system architectures [1]-[6] have been extensively studied for non-contact human vital-sign detection in the last decade. In order to improve the sensitivity of the radar system, a higher frequency band, such as Ka-band [2], [3] or 60 GHz [6], has been designated as the operating frequency of the Doppler radar system. However, since the Ka-band radar system in [2], [3] was mainly implemented by the commercial off-the-shelf parts, the mass production would be a problem to make the vital-sign radar practical. Moreover, for the 60-GHz radar [3], the linear approximation of the base-band signal is not valid any more. It will lead to serious harmonic and intermodulation effects [7].

In this paper, a commercial 24-GHz radar system chip in Silicon Germanium technology is adopted to implement a compact vital-sign Doppler radar module. Two antenna arrays with 4 by 5 elements are designed and treated as the transmitting and receiving antennas of the radar system. In addition, the output base-band signals of the radar chip are acquired by a microcontroller (MCU) with a 10-bit analog-to-digital conversion (ADC) resolution. The digital signals are then sent to the laptop computer via a Bluetooth module. The developed 24-GHz radar module has been successfully demonstrated to detect the respiration and heartbeat rates of a human adult.

2. Design of 24-GHz Radar Module

The system block diagram of the developed 24-GHz Doppler radar for vital sign detection is shown in Fig. 1. The kernel component of this module is the 24-GHz radar transceiver chip, Infineon BGT24MTR11, which adopts the homodyne radar system architecture as similar to that in [1].

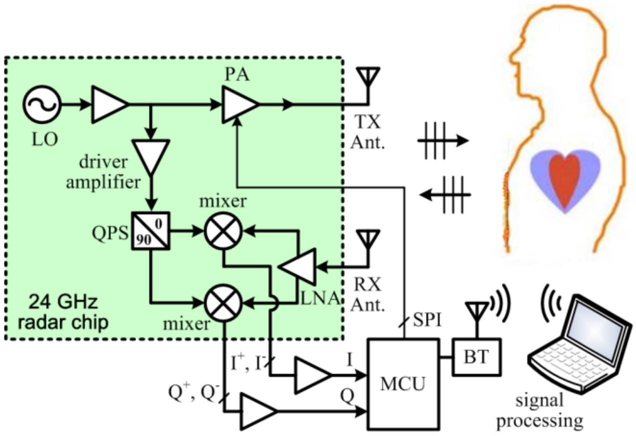

Fig. 1. System block diagram of the developed 24-GHz Doppler radar module.

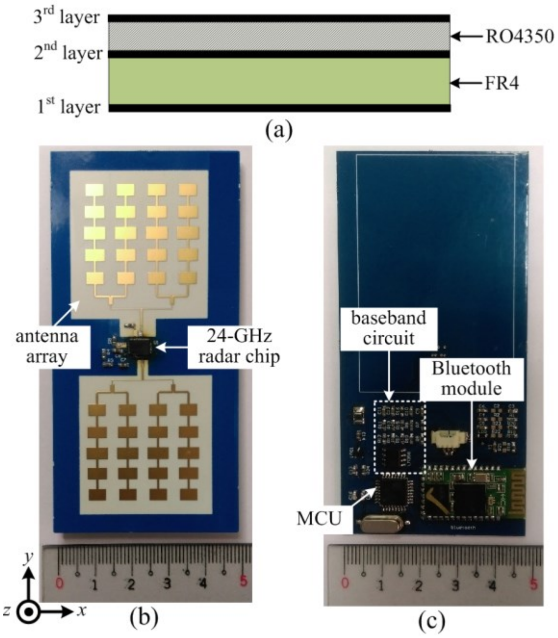

Fig. 2. (a) The structure of the stacked 3-layered PCB substrate. (b) Top-view and (c) bottom-view photographs of the developed 24-GHz Doppler radar module.

The radar chip transmits 24-GHz continuous wave (CW) via a series-fed antenna array with 4 by 5 elements. As the transmitted wave hits the moving chest of the subject under test (SUT), the wave will be phase modulated by the moving respiration and heartbeat variations, and then scattered back to the module. The phase-modulated wave is acquired by the receiving antenna array, and then directly

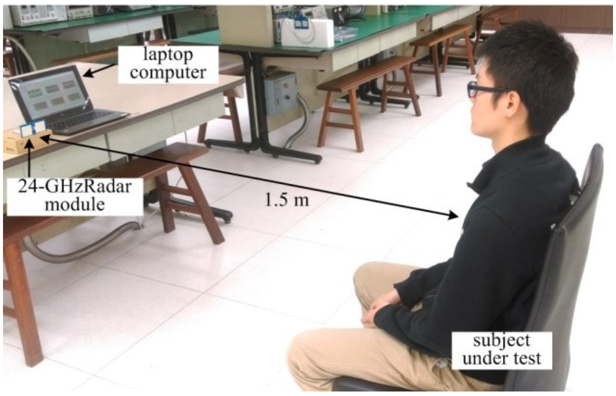

Fig. 3. Measurement scenario of the developed 24-GHz Doppler radar module.

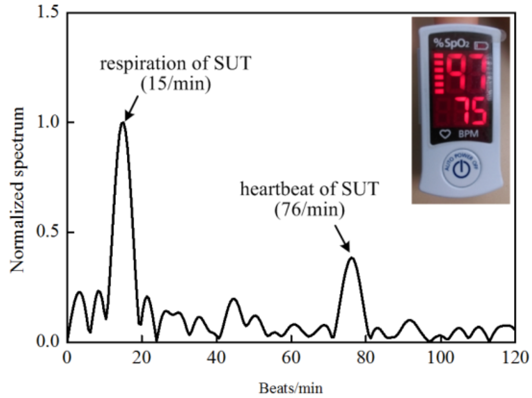

Fig. 4. Measured normalized frequency spectrum of the base-band signals.

converted to differential in-phase (*I*) and quadrature-phase (*Q*) base-band signals. After the proper amplification, the analog signals convert to digital signals by the microcontroller (MCU), Atmel ATmega 328p, with a 10-bit ADC resolution. Finally, the digitized signals are sent to the laptop computer via a Bluetooth module and processed by the NI LabVIEW.

The developed 24-GHz radar module was implemented on a printed-circuit board (PCB) stacked up by Rogers RO4350 and FR4 substrates as shown in Fig. 2 (a). The top- and bottom-view photographs of the radar module are shown in Fig. 2 (b) and (c), respectively. The transmitting and receiving antenna are designed on the RO4350 substrate with a thickness of 0.254 mm, a dielectric constant of 3.48, and a loss tangent of 0.0037. The simulated antenna gain is about 17.1 dBi and the corresponding E-plane (*yz*-plane) and H-plane (*xz*-plane) beam widths are about 24° and 20°, respectively. The 24-GHz radar chip is also put on the RO4350 substrate as close as possible to antennas for transmission loss reduction. In addition, the base-band circuitry, MCU, and Bluetooth module are realized on the backside of the module as shown in Fig. 2 (c), namely on the FR4 substrate. The size of the developed module is 5 cm×10 cm.

3. Experimental Results

The measurement scenario of the developed 24-GHz noncontact vital-sign radar system is setup as illustrated in Fig. 3. The subject under test (SUT), a human adult, breathes normally and seats 1.5 m from the radar. The measured time-domain results of I and Q channels are sent into the laptop computer, and then combined by the complex signal demodulation method [8], namely $I(t)+jQ(t)$, to form a complex number in NI LabVIEW. After performing the fast Fourier transformation (FFT), the normalized spectrum is shown in Fig. 4. It clearly reveals that the respiration rate of the SUT is 15 beats per minute and the heartbeat rate is 76 beats per minute. The heartbeat rate agrees the measured results by the finger pulse sensor, 75 beats per minute, very well as given in the inset figure of Fig. 4.

4. Conclusion

In this paper, a compact 24-GHz Doppler radar module is developed to monitor the respiration and heartbeat of a human adult. The heartbeat rate agrees that acquired by the finger pulse sensor very well. The developed radar module can be further applied to monitor the physiological parameters of the adults suffered from the obstructive sleep apnea syndrome (OSAS).

Acknowledgment

This work was supported by the Ministry of Science and Technology of Taiwan under Grant MOST 104-2221-E-011-031.

References

[1] A. D. Droitcour, O. Boric-Lubecke, V. M. Lubecke, J. Lin, and G. T. A. Kovacs, "Range correlation and I/Q performance benefits in single-chip silicon Doppler radars for noncontact cardiopulmonary monitoring," *IEEE Trans. Microw. Theory Tech.,* vol. 52, pp. 838–847, Mar. 2004.

[2] Y. Xiao, J. Lin, O. Boric-Lubecke, and V. M. Lubecke, "Frequency-tuning technique for remote detection of heartbeat and respiration using low-power double-sideband transmission in the Ka-band," *IEEE Trans. Microw. Theory Tech.,* vol. 54, pp. 2023–2032, May 2006.

[3] C. Li, Y. Xiao, and J. Lin, "Experiment and spectral analysis of a low-power Ka-band heartbeat detector measuring from four sides of a human body," *IEEE Trans. Microw. Theory Tech.,* vol. 54, pp. 4464–4471, Dec. 2006.

[4] F.-K. Wang, C.-J. Li, C.-H. Hsiao, T.-S. Horng, J. Lin, K.-C. Peng, J.-K. Jau, J.-Y. Li, C.-C. Chen, "A novel vital-sign sensor based on a self-injection-locked oscillator," *IEEE Trans. Microw. Theory Tech.,* vol. 58, pp. 4112–4120, Dec. 2010.

[5] I. Mostafanezhad and O. Boric-Lubecke, "Benefits of coherent low-IF for vital signs monitoring using Doppler radar," *IEEE Trans. Microw. Theory Tech.,* vol. 62, pp. 2481–2487, Oct. 2014.

[6] T.-Y. J. Kao, Y. Yan, T.-M. Shen, A. Y.-K. Chen, and J. Lin, "Design and analysis of a 60-GHz CMOS Doppler micro-radar system-in-package for vital-sign and vibration detection," *IEEE Trans. Microw. Theory Tech.,* vol. 61, pp. 1649–1659, Apr. 1649.

[7] C. Li and J. Lin, "Optimal carrier frequency of non-contact vital sign detectors," in *IEEE MTT-S Int. Microwave Symp. Dig.*, Jun. 2007, pp. 281-284.

[8] C. Li and J. Lin, "Random body movement cancellation in Doppler radar vital sign detection," *IEEE Trans. Microw. Theory Tech.,* vol. 56, pp. 3143–3152, Dec. 2008.