Proceedings of ISAP 2014, Kaohsiung, Taiwan, Dec. 2-5, 2014

Antenna Radiation Pattern Effects on a Short-Range Vibration-Detection Radar System

Chien-Ming Nieh, Tien-Yu Huang, and Jenshan Lin
Department of Electrical and Computer Engineering, University of Florida, Gainesville, FL, 32611, USA

***Abstract* – This paper presents a 5.8 GHz Doppler noncontact vibration-detection radar system with 2X2 patch array antennas and single patch antennas. Two different types of antennas are used on both transmitter (Tx) and receiver (Rx) sides, alternately. An actuator is connected with a 16 cm x 14 cm metal plate and generates a 1 Hz sinusoidal movement with 1 mm peak-to-peak displacement. The system can successfully detect a target's vibration when it is vertically misaligned with the target by 31° and placed at 0.5 m away. The system with the broad beamwidth antennas shows the best result.**

***Index Terms* — Doppler radar system, Patch antenna, Sensor**

I. INTRODUCTION

Doppler noncontact vibration-detection radar system has drawn lots of attention recently, and many research results have been reported in this field [1]-[5]. It detects a target's vibration and is suitable for many applications, such as infant monitoring, home security, animal vital sign detection, and mechanical vibration detection. On the transmitter (Tx) side, a continuous-wave (CW) signal is transmitted to a target. The reflected signal modulated by the target's movement is received on the receiver (Rx) side and down-converted to the baseband. The baseband signal is analyzed after an A/D converter (ADC). The detected signal is distorted when a target is at the null detection point [1]. Quadrature signals with a complex signal demodulation (CSD) method are introduced to fix this problem [2]. Higher antenna gain achieves better signal to noise ratio (SNR) but sacrifice the detection coverage. An adaptive beam-steering antenna has been implemented to achieve good SNR without sacrificing the antenna coverage [5]. The effect of the antenna radiation beamwidth when the system is misaligned, however, has not been studied even though it is a practical scenario when measuring human vital signs. The small vital sign area can be easily misaligned with antenna beam when the target's posture changes. Although the Tx and Rx antennas should be reciprocal based on the radar equation [6], the actual measurement results indicate that some other factors might cause different effects on Tx and Rx. This paper compares two different antennas (a single patch and a 2X2 patch array) on Tx and Rx to detect the vibration movement when the antenna and target are misaligned.

II. SYSTEM IMPLEMENTATION

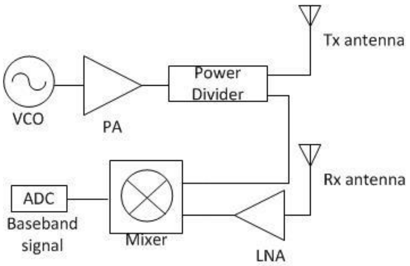

Fig. 1. Architecture of Doppler noncontact vibration-detection radar system

Fig. 1 shows the architecture of the Doppler noncontact vibration-detection radar system. The CW signal from the voltage control oscillator (VCO) is amplified by the power amplifier (PA). It is then equally split and sent to the Tx antenna and the mixer's local oscillator (LO) port. The received signal through the Rx antenna is amplified by a low noise amplifier (LNA) and down-converted in the mixer. The range correlation effect significantly reduces the phase noise of the oscillator [1]. The baseband signal, B(t), contains the vibration information shown as follows:

$$B(t) \approx \cos\left[4\pi x(t)/\lambda + \Delta\phi + \theta\right] \qquad (1)$$

where $x(t) = A \cdot \sin(\omega t)$ is the vibration movement, λ is the wavelength of the carrier, $\Delta\phi$ is the accumulated phase residue, and θ is the phase delay in the Rx. The vibration information can be extracted by the CSD method.

Fig 2 shows the simulated radiation patterns of the 2X2 patch array antenna with 42° 3-dB beamwidth and the single patch antenna with 91° 3-dB beamwidth in ANSYS HFSS. The antennas and the radar transceiver are both implemented on Rogers 4350B laminates with a thickness of 30 mils. The antenna input reflection coefficients are measured by an

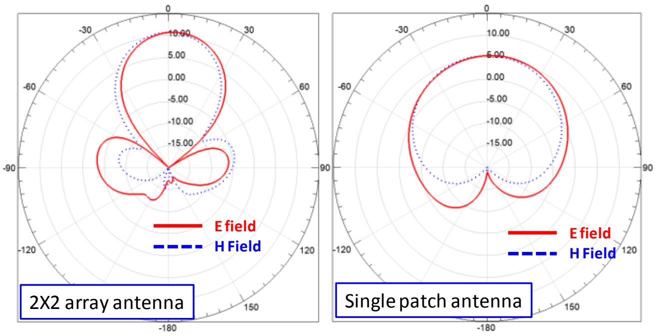

Fig. 2. Simulated radiation patterns of the 2X2 array antenna (left) and the single patch antenna (right) in ANSYS HFSS

Agilent vector network analyzer E8361. Fig. 3 shows the measured reflection coefficients of a single patch antenna in dotted blue line and a 2X2 patch array antenna in solid red line.

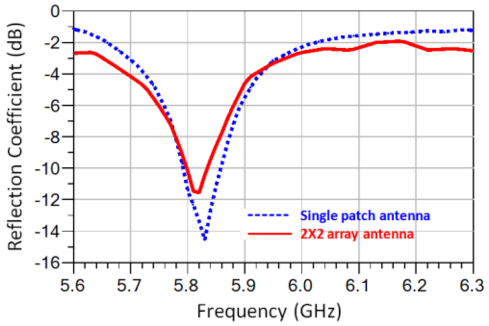

Fig. 3. Measured reflection coefficients of the single patch antenna (blue dotted line) and the 2X2 array antenna (solid red line).

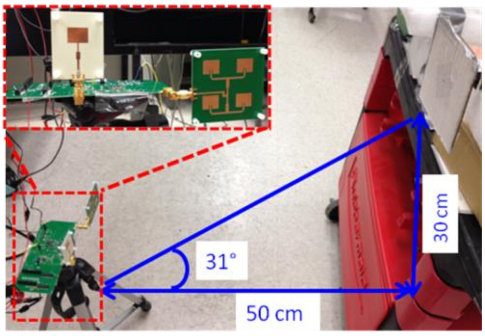

Fig. 4. Measurement setup.

III. EXPERIMENT AND ANALYSIS

Fig. 4 shows the measurement setup. A 16 cm x 14 cm metal plate is attached to an actuator. The actuator generates a 1 Hz sinusoidal movement with 1 mm peak-to-peak displacement. The radar system is 31° vertically misaligned with the target and placed at 0.5 m away. Two single-patch antennas and two 2X2 array antennas were fabricated. The signals are measured at four different combinations of antennas on Tx and Rx and the results are shown in Fig. 5. Vibration information is extracted by CSD method in frequency domain [2]. In Fig. 5(a), two 2X2 array antennas are used on both Tx and Rx. The signal cannot be detected since at 31° the gain of the 2X2 array drops significantly. In Fig. 5(b) and Fig. 5(c), a single patch antenna is used on Tx or Rx and a 2X2 array antenna is used on the other. The combined antenna gains at 31° are the same in either case. Nevertheless, Fig. 5(b) shows a larger SNR than Fig. 5(c). Several follow-up experiments indicate that the broader beamwidth or higher antenna gain at the target direction plays a more important role at Tx than at Rx. One possible reason is the multiple reflections between the target and the antenna in short-range detection. The reradiated signal from the antenna depends on the termination impedance. The Tx antenna is directly connected to the PA output which typically has smaller impedance and would reradiate more signal power back to the target. In this case the broader beamwidth single-patch antenna which has the higher gain at target direction is preferred to be placed on the Tx to improve overall SNR. In Fig. 5(d), two single patch antennas are used on Tx and Rx and the SNR is the largest due to the highest combined antenna gain at 31°. Thus, the system with broad beamwidth antennas is more robust for human vital sign detection since the human vital sign area is very small.

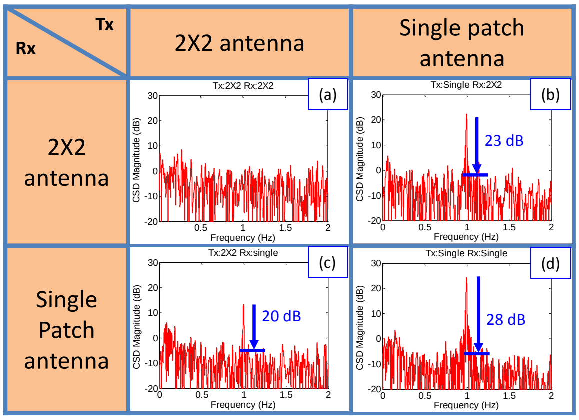

Fig. 5. Vibration signals measured at four different combinations of antennas on Tx and Rx.

IV. CONCLUSION

A 5.8 GHz Doppler noncontact vibration-detection radar system using antennas of different beamwidths are experimented. As expected, the antennas with broader beamwidth is more robust in detection when there is a misalignment between the antenna beam and the target. Unexpectedly, it was observed that placing the antenna with broader beamwidth on Tx achieves better SNR than placing it on Rx. A possible reason is suggested, but further research and verification will be needed. The results provide useful guidelines for designing a radar system for short-range human vital sign detection.

ACKNOWLEDGMENT

The authors would like to thanks Maxim, Hittite Microwave, and Rogers for providing microwave devices and the laminate substrates.

REFERENCES

[1] A. D. Droitcour, O. Boric-Lubecke, V. M. Lubecke, J. Lin, and G. T. A. Kovac, “Range correlation and I/Q performance benefits in single-chip silicon Doppler radars for noncontact cardiopulmonary monitoring,” *IEEE Trans. Microw. Theory Techn.*, vol. 52, no. 3, pp. 838–848, Mar. 2004.

[2] C. Li and J. Lin, “Complex signal demodulation and random body movement cancellation techniques for non-contact vital sign detection,” in *IEEE MTT-S Int. Microw. Symp. Dig.*, Atlanta, GA, Jun. 2008, pp. 567–570.

[3] F.-K. Wang, C.-J. Li, C.-H. Hsiao, T.-S. Horng, J. Lin, K.-C. Peng, J.-K. Jau, J.-Y. Li, and C.-C. Chen, “A novel vital-sign sensor based on a self-injection-locked oscillator,” *IEEE Trans. Microw. Theory Techn.*, vol. 58, no. 12, pp. 4112–4120, Dec. 2010.

[4] J. Tu and J. Lin, “Respiration harmonics cancellation for accurate heart rate measurement in non-contact vital sign detection,” in *IEEE MTT-S Int. Microw. Symp. Dig.*, Seattle, WA, Jun. 2013.

[5] C.-M Nieh and J. Lin, “Adaptive beam-steering antenna for improved coverage of non-contact vital sign radar detection,” in *IEEE MTT-S Int. Microw. Symp. Dig.*, Tempa, FL, Jun. 2014.

[6] D. M Pozar, “Introduction to microwave systems,” in *Microwave Engineering*, 4th ed. New York: John Wiley & Sons, 2012.