A Dual-band FMCW Radar for Through-wall Detection

Byungjoon Kim, Duksoo Kim, Youngjoon Lim, and Sangwook Nam
School of Electrical and Computer Engineering and INMC
Seoul National University
Seoul, Korea
[bjkim; dskim; yjlim] @ael.snu.ac.kr, snam@snu.ac.kr

Eun-Hyuk Kwak and Boo-Gyoun Kim
School of Electric Engineering
Soongsil University
Seoul, Korea
ehkwak@ssu.ac.kr, bgkim@e.ssu.ac.kr

Hwanseok Yeo and Jaeha Kim
School of Electrical and Computer Engineering
Seoul National University
Seoul, Korea
[hsyeo; jaeha]@mics.snu.ac.kr

***Abstract*—In this paper, a dual-band, frequency-modulated continuous-wave (FMCW) radar for short-range through-wall detection is proposed and implemented. This radar adopts a shared-aperture antenna technique for reducing antenna area and high-speed chirping to avoid flicker noise. It operates at the S-band (3 GHz) and the X-band (9 GHz), with 486 MHz chirp bandwidth and 860 MHz chirp bandwidth, respectively. The chirp rates are 11,050 GHz/s and 22,000 GHz/s at the S- and X-bands, respectively. The radar has successfully detected a target through a wooden wall.**

***Keywords*—Frequency-modulated continuous-wave (FMCW), Short-range radar, Through-wall radar.**

I. INTRODUCTION

Through-wall detection has been an interesting topic in recent research [1]. A frequency-modulated continuous-wave (FMCW) radar system is one candidate radar system for through-wall detection [2]. In an FMCW radar system, a beat frequency is used to measure a target range, since the beat frequency is proportional to the time-of-flight. Therefore, the intermediate frequency (IF) filters can be used to eliminate the out-of-range clutter. The FMCW radar with high-quality factor IF filters, which can fully attenuate beat frequency signals from out-of-range clutter, thus achieving high dynamic range and high sensitivity, with low power consumption.

Although conventional single-band FMCW radar systems can detect a hidden target well, sometimes they do not work when the wall has a large propagation attenuation in a specific frequency, and this notch frequency corresponds to radar's operating frequency. A dual-band FMCW radar system is therefore required to overcome this problem.

In this paper, a dual-band FMCW radar system for detecting a target through a wall in short-range is proposed and implemented. The implementation and measurement results are described in Section II; conclusion and future work are discussed in Section III.

II. IMPLEMENTATION AND MEASUREMENT RESULTS

Because wall attenuation is proportional to radar operation frequency, and range resolution is inversely proportional to chirp bandwidth, radar operation frequency and chirp bandwidth are very important for through-wall detection [3],[4]. The radar operation bands we chose are the S-band and the X-band; the S-band has low wall attenuation compared to higher-frequency bands, and requires a smaller antenna size compared to lower-frequency bands; and the X-band easily provides wider bandwidth, with a compact-sized antenna.

Although dual-band radar provides great utility, it requires a massive volume because it uses four antennas for supporting the transmitting and receiving of the S- and X-bands. S-band antennas, in particular, require a large area, because the antenna's physical size is limited by the wavelength [5]. Therefore, for this study we adopted a shared-aperture antenna technique, which allows an S-band and an X-band antenna to share the same antenna area. The result was that the total antenna area was dramatically decreased: the implemented antenna size was 5.3 cm (width) by 8.3 cm (length). The antenna has more than 20% bandwidth at the S-band, and more than 30% bandwidth at the X-band, with 5.4 dBi gain and 8.7 dBi gain, respectively.

Though a shared-aperture antenna technique reduces the antenna area, it does require two physically different ports for S- and X-band feeding. Band selection switches are therefore required; two switches were used.

Most of the components are shared in S- and X-band mode operation thanks to FMCW radar's characteristics, excluding S-band low-noise-amplifiers (LNAs), X-band LNAs, and an X-band power-amplifier (PA) for meeting noise figure (NF) and power specifications. A dual-band FMCW radar architecture is shown in Fig. 1.

In this radar system, a homodyne architecture was adopted to reduce the number of components. Although the homodyne architecture has various advantages, it does have a classical

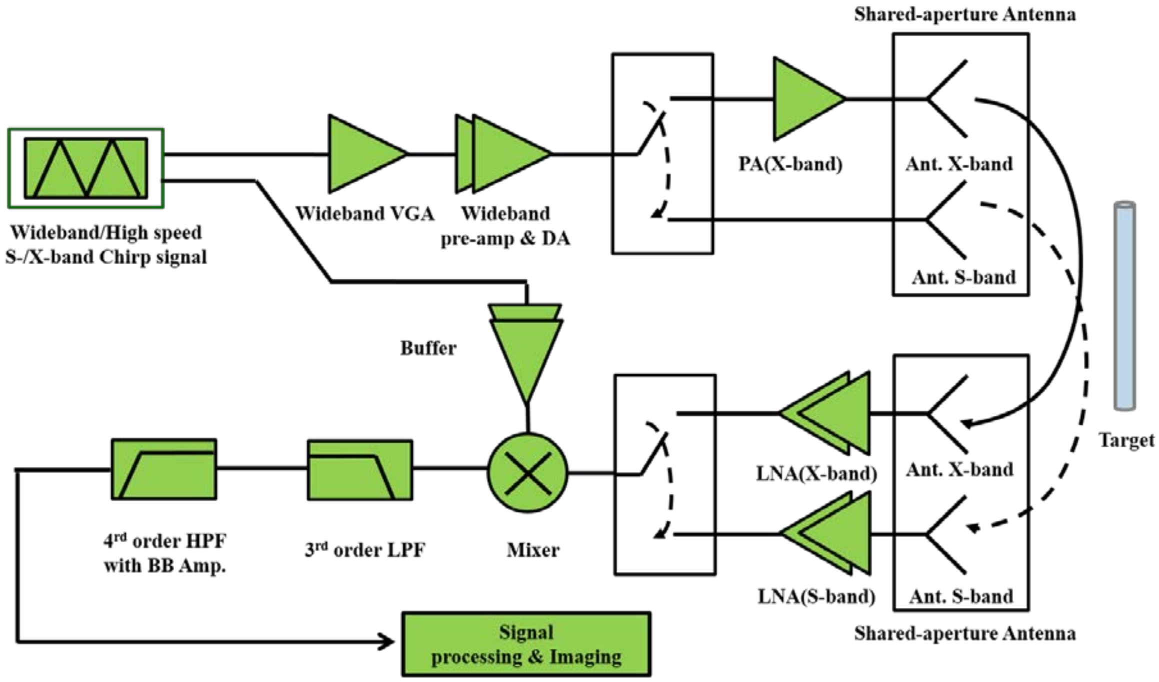

Fig. 1. A dual-band FMCW radar transceiver architecture.

problem: flicker noise (1/f noise) [6]. Flicker noise dramatically degrades receiver sensitivity. The flicker noise problem is solved by carefully choosing a chirp rate.

The beat frequency is calculated as:

$$f_{IF} = \frac{2R}{c} * C_R, \quad (1)$$

where f_{IF} is beat frequency, R is target range, c is the speed of light, and C_R is chirp rate. To avoid the beat frequency occurring below 80 kHz when the radar detects a 1.2 m-distant target, the chirp rate must be faster than 10,000 GHz/s. Therefore, a chirp source that has an 11,050 GHz/s chirp rate in S-band mode and a 22,000 GHz/s chirp rate in X-band mode was developed. The developed chirp source bandwidth is 486 MHz and 860 MHz in the S- and X-bands, respectively. A 486-MHz chirp bandwidth corresponds to a 30.9-cm resolution, and an 860-MHz chirp bandwidth corresponds to a 17.4-cm resolution.

The receiver gain is 49 dB and 59 dB in the S-band and X-band, respectively, while the NF is 4 dB and 3.5 dB, respectively. A High Pass Filter (HPF) was combined with a conventional second-order active RC filter with operational amplifiers and a reconfigurable second-order Gm-C filter. A second-order Gm-C filter was designed with high linearity to deal with amplified wall reflection and target reflection. A third-order intercept point (IIP3) was 19.4dBm. The transmitter gain is 27 dB and 33 dB in the S- and X-bands, respectively, and the maximum transmitter power is over 17 dBm and over 15 dBm in the two bands, respectively. Table 1 shows the radar block specifications.

Figure 2 shows the radar test results in free space. The target was 0.51-m (width) by 0.51-m (length) square metal plate. Figure 2-(a) shows the S-band response. The measured beat frequency of the 1.4-m target was 115 kHz, and the 2.8-m target was 224 kHz in S-band operation. Considering the S-band chirp rate, then 115 kHz corresponds to a 1.48-m target, and the 224-kHz target corresponds to 2.92 m. The range error rate is under 5.7 %. Figure 2-(b) shows an X-band response. The measured beat frequency of the 1.25-m target was 185 kHz, and the 2.5-m target was 380 kHz in X-band operation.

Figure 3 shows the radar test results for through-wall target

Table 1: RX and TX performance summary

Radar Block Specifications		
Band	S-band	X-band
Antenna Gain	5.4 dBi	8.7 dBi
Antenna Bandwidth	> 20 %	> 30 %
Chirp Bandwidth	486 MHz	860 MHz
Chirp Rate	11,050 GHz/s	22,000 GHz/s
RX Gain	49 dB	59 dB
RX NF	4 dB	3.5 dB
TX Gain	27 dB	33 dB
TX Pout	17 dBm	15 dBm

(a) (b)

Fig. 2. An intermediate frequency (IF) spectrum: (a) S-band (1.4-m target, 115 kHz beat frequency); (b) X-band (1.25-m target, 185 kHz beat frequency)

(a) (b)

Fig. 3. An IF spectrum: A target with a woodem wall: (a) S-band (2.8-m target, 224 kHz beat frequency); (b) X-band (1.5-m target, 265 kHz beat frequency)

detection. The wall material was wood, and the target was the same in free space. Wall reflection and target reflection are both shown in the radar output spectrum. Figure 3-(a) shows the S-band response. The measured beat frequency of the 2.8-m target is 224 kHz. Figure 3-(b) shows the X-band response. The measured beat frequency of the 1.5-m target is 265 kHz. These results are in good agreement with the theory.

III. CONCLUSION

This study proposes a dual-band, homodyne FMCW radar for short-range through-wall detection, and implements a prototype radar. This radar operates at S-band (3 GHz) and X-band (9 GHz) with high chirping rates: the S-band chirping rate is 11,050 GHz/s, and the X-band chirping rate is 22,000 GHz/s, with 486 MHz chirp bandwidth and 860 MHz bandwidth, respectively. A 486-MHz bandwidth corresponds to a 30.9-cm resolution, and an 860-MHz bandwidth corresponds to a 17.4-cm resolution. This radar can detect a hidden target in both operation modes. Future work will include a high-loss material wall through a detection test.

ACKNOWLEDGMENT

This work was partly supported by the ICT R&D program of MSIP/IITP (No. 14911-01004, SDR Radar Sensor Platform Development).

REFERENCES

[1] Y. Lim and S. Nam, “Target-to-Clutter ratio enhancement of Images in through-the-wall radar using a radiation pattern-based delayed-sum algorithm,” *Journal of Electromagnetic engineering and Science*, vol. 14, no. 4, pp. 405-410, Dec. 2014.

[2] G. L. Carvat, L. C.Kempel, E. J. Rothwell, C. M. Coleman, and E. L. Mokole, “A through-dielectric radar imaging system,” *IEEE Trans. Antennas Propag*., vol. 58, no. 8, pp. 2594-2603, Aug. 2010.

[3] N. Maaref, P. Millot, and C. Pichot, “Ultra wide Band Radar System for Through-The-Wall Microwave Localization and Imaging,” in *Proc. 8th European Conference on Synthetic Aperture Radar (EUSAR)*, June 2010.

[4] F. Fioranelli, et al., "Through-The-Wall Detection With Gated FMCW Signals Using Optimized Patch-Like and Vivaldi Antennas," *IEEE Trans*. *Antennas Propag*., vol. 63, no. 3, pp. 1106-1117, March 2015.
[5] S.-S. Zhong et al., "Tri-band dual-polarization shared-aperture microstrip array for SAR applications," *IEEE. Trans. Antennas Propag*., vol. 60, no. 9, pp. 4157-4165, Sep. 2012.
[6] L. Besser and R. Gilmore, Practical RF Circuit Design for Modern Wireless Systems, London: Artech House, 2003.