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A novel monostatic concurrent multiband radar front-end architecture and its dual-band implementation

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A B S T R A C T

This paper proposes a novel monostatic concurrent multiband radar front-end architecture that can work in several independent bands simultaneously. Compared with the conventional single-band radar, multiband radar has the potential to support different modulation modes in independent frequency bands and multi-functional integration, and has a good ability to adapt to complex electromagnetic environment and flexible applications. In order to demonstrate the validity of this proposed multiband radar front-end architecture, the corresponding dual-band radar and two single-band radar prototypes are fabricated and measured. A good agreement of measured results between the dual-band and two single-band radar front-ends validates the effectiveness and reliability of the proposed new radar architecture.

1. Introduction

Generally, radar sensors transmit electromagnetic energy directionally and receive reflected echoes to extract the target information (velocity, distance, vibration, angular position, etc.) [1]. It can be classified as continuous-wave (CW) and pulsed radars. Unmodulated CW radars can accurately measure the speed of the target, but cannot get the target distance [2]. Frequency modulation continuous wave (FMCW) radars and modulated pulsed radars are often used to get both distance and speed information [2]. Over the recent decades, many radar systems for high-performance noncontact liquid level monitoring [3,4], automotive radar sensing [5–7], weather measurement [8] and life detection [9–15] have been playing important roles in smart industrial and medical applications. Among these applications, vehicle speed and range measurement is more and more popular in autonomous cruise control (ACC) system in recent years. The radar-based ACC functionality provides essential information of traffic situations around the vehicle, for achieving stop and go operation, collision mitigation and lane change assistance. In order to achieve these functions, various short- and long-range radar sensors have been widely studied so far. For example, ultra-wideband radar sensors [7] and miniaturized 24 GHz narrow band radar sensor based on six-port technology [16] were proposed for high-accuracy short-range detection; while automotive safety applications are accomplished by using mixed short- and long-range radars [5]. The first dual-band radar sensor based on SiGe BiCMOS technology has been proposed in [6], even though it uses switches to select the operating band. Extensive researches and developments on highly integrated silicon-based radar sensor have been reported [17–19]. Therefore, it is a new trend that the next-generation radar sensors require multiband operation and multi-functional integration.

Other important applications of radar sensors are life detection [9,12] and healthcare monitoring [10] that combines radar-sensing technology with biomedical engineering. It can detect human physiological information (respiration, heartbeat, body movement, etc.) behind brick walls (or ruins) with keeping noncontact state. For example, in order to search and rescue earthquake survivors, sensitive microwave radar sensors for life-detection and surrounding rubble structure estimation have been reported in [9,12]. Besides, a high accuracy radar sensor for remote respiration and heartbeat vital-sign monitoring has been presented in [10]. However, the interference of operator or ground may reduce system's accuracy and sensitivity in the actual rescue operations in life-detection radars [9,12]. Some solutions in [11,20] were proposed to overcome this problem. In particular, a novel method of dual-frequency continuous-wave suppression technique was introduced in [11]. This system uses two independent radar sensors with different frequencies of 5.75 GHz and 35 GHz to distinguish movement signals of the target from those of the operator with the help of adaptive filtering method. A multiband FMCW radar module for distance measurement [21], tri-band radar system for monitoring vital signs [22], and multiband coherent radar system [23] were demonstrated using switches, several radars working at different frequencies,

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or photonic technologies. Consequently, it is obvious that multiband radars could be effective solutions for accurate measurement in complex electromagnetic environments.

As a generalized concept of the dual-frequency (dual-band) radars, a novel monostatic concurrent multiband radar front-end architecture is proposed in this paper. The multiband concurrent radar is able to work simultaneously in several independent bands. Compared with the conventional single-band radar, this proposed multiband radar has several features, such as high target-detection probability, accurate velocity measurement, strong anti-interference ability, good adaptability for complex electromagnetic environment, etc. The proposed new architecture introduces multiband couplers to realize the isolation between the receiving and transmitting channel and multiplexers for the isolation of each band rather than using switches with large time delay, multiple sensors with high cost or photonic technologies with large dimensions. In order to prove the validity of this proposed multiband radar front-end architecture, a dual-band radar prototype for speed measurement is designed and measured. In addition, two conventional single-band 13.5- and 24-GHz radars are also made for the purpose of comparison. A good agreement between the proposed dual-band and two conventional single-band radars validates our proposed multiband radar front-end architecture.

2. Descriptions of the proposed monostatic concurrent multiband radar architecture

As shown in Fig. 1, the proposed monostatic concurrent multiband radar front-end architecture contains multiplexers, multiband coupler and low noise amplifier (LNA), multiband frequency generator, multiband antenna, and multiband (multi-channel) mixer. Among these components, the multiplexers are used to combine multiple oscillator signals and send to the multiband coupler, or to distribute local oscillator signals and received signals to the down conversion mixer. The multiband coupler is the key component in this new architecture for realizing the isolation between receiver and transmitter, which avoids the use of additional multiple sensors or switches and makes the system have a simple and monocratic form. Note that the traditional monostatic radar and this multiband radar architecture are not suitable for FMCW radar due to the local oscillator (LO) signals will leak to the receive channels. The multi-function radar sensor can be accomplished using different modulation modes in each independent frequency bands (f_1, f_2, … f_n) if sufficient transmitter-receiver isolation can be provided. Leakage cancellation and analysis for FMCW radar are introduced in [24–26]. The multi-frequency signals can be generated by the N-way oscillators and merged as the LO signal by a multiplexer, and then the signal is divided into two parts equally via the multiband coupler. One path of the multi-frequency signals is radiated through the antenna as the transmitted radar signal, while another path from the multiband coupler is served as the multi-frequency LO signal for the multiband mixer (or separated into N-way single-frequency signals by multiplexer, and then discrete signals served as LO signals for the separate channels).

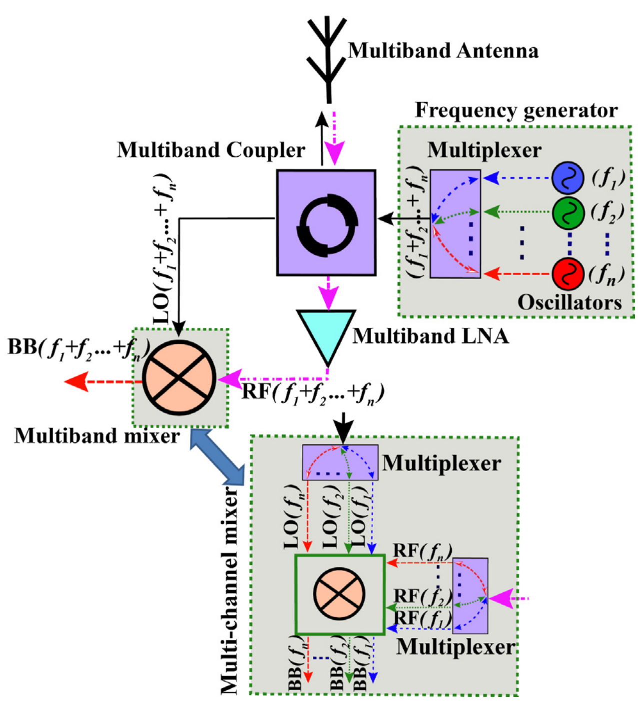

Fig. 1. The block diagram of the proposed monostatic concurrent multiband radar front-end architecture.

After the transmitting process, the echoes from specific targets are received by the same antenna and transmitted through the coupler with good isolation from the transmitter's channel. Then the received signals are amplified by the multiband LNA, then injected into the multiband mixer, mixed with the multi-frequency LO signals (or separated into N-way discrete signals according to the channels frequencies, and injected into the multi-channel mixers, mixed with the N-way LO signals respectively). Note that after mixing process, the demodulated signals (i.e. the base band (BB) signals) of different carrier frequencies are intermingled for multiband mixer, but these signals are separated for multi-channel mixers.

3. Design of the corresponding single- and dual-band radar sensors

3.1. The architecture of single- and dual-band radars

Considering the above challenges and the design complexity of the devices constructing this multiband radar front-end architecture, a dual-band prototype for speed measurement is designed and made for a simple and direct verification of this proposed monostatic concurrent multiband radar architecture. The dual-band prototype consists of several single- and dual-band components including antennas, oscillators, diplexers, coupler, LNA, and mixer. Meanwhile, two conventional single-band 13.5- and 24-GHz radar front-ends are made for the purpose of comparison. Two industrial-application typical frequencies of 13.5 and 24 GHz are chosen that lies in Ku band and K band in this fabricated dual-band radar front-end architecture.

The block diagram of the conventional single-band radar working at 13.5 or 24 GHz is illustrated in Fig. 2(a). There is only one block diagram to present the two single-band radar sensors due to the same configuration. The 13.5 or 24 GHz signal can be generated from the oscillator, and then be divided into two identical signals through the single-band coupler. One signal from the coupler is radiated through the antenna to the specific target. The reflected echoes are received by the same antenna and pass through the coupler, and then amplified by the LNA acting as the RF signal for the mixer. Another signal from the coupler acts as the LO signals for the mixer. The BB signals that demodulated through the mixer contains the target's information. The information is filtered through the low-pass filter in order to filter out high-frequency clutters.

To extend the traditional single-band radar to dual-band one, the key is how to implement separation of the two frequency bands and extend single-band coupler to dual-band operation. The block diagram of the novel dual-band radar architecture is shown in Fig. 2(b). Since the dual-band radar is a special case of the multiband radar proposed in Section 2, the operation principle of this dual-band radar can also be directly deduced from the one of multiband realization. The same chips of the oscillators, the dual-band LNA, and mixer are used in the dual-band radar front-end. The types of the used chips are listed in Table 1. For speed measurement, the output BB signals of the two different