Compact FMCW Radar for a UAS Sense and Avoid System

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***Abstract*—U.S. Federal Avionics Administration (FAA) regulations limit the use of unmanned air systems (UAS) in commercial and private industry because of the potential danger that they pose to other aircraft. The development of an onboard Sense and Avoid (SAA) system is necessary for UAS to share the same airspace as other aircraft. This paper presents the design and fabrication of a radar sensor designed for use as part of a reactive path planning system. The radar is a Frequency Modulated Continuous Wave (FMCW) type with two receive channels. This enables monopulse processing to provide both range and bearing information of detected targets. Without connectors or antennas, it weighs 46 g, is 7.6 x 5 x 3.8 cm in size, and costs less than $100 when built in quantities of 100 or more. The radar has been tested using outdoor targets and is currently being integrated with a UAS autopilot and collision avoidance algorithm for airborne testing.**

I. Introduction

Unmanned air systems (UAS) are currently transitioning from military to civil applications. With a potentially multi-billion dollar market opening up over the next decade, radars will be exploited in commercial use for remote sensing, altimetry, bridge integrity monitoring, land surveying, collision avoidance, and numerous other applications. UAS will not be approved by the FAA for generalized commercial applications unless they can prove collision avoidance capabilities [1], [2].

SAA systems are classified into cooperative and non-cooperative categories. For cooperative systems, Automatic Dependent Surveillance-Broadcast (ADS-B) systems are currently a predominant choice [3], [4]. For intruder aircraft and other non-cooperative objects, radar or other optical detection systems must be used. UAS are limited in the amount of extra payload that they can carry and attributes such as size and weight are critical in the design of the radar. There is a good deal of work in the literature on compact radars, particularly for automotive collision avoidance [5].

For UAS sense and avoid, design requirements are different than for other common radar applications. Size and weight are even more critical than for automotive applications, and performance of the reactive path planning algorithm is enhanced if the radar can provide bearing information. Based on these considerations, we present a design for a radar with mechanical and RF performance targeted to UAS sense and avoid applications.

II. Design

The overall SAA system will include a radar sensor, a data processing module, and an autopilot as shown in Figure 1.

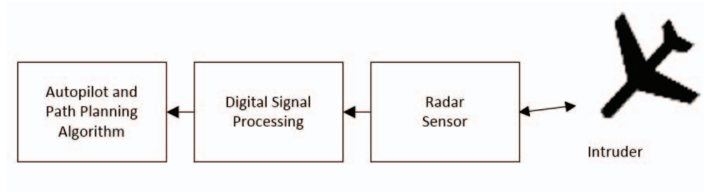

Fig. 1. SAA system block diagram.

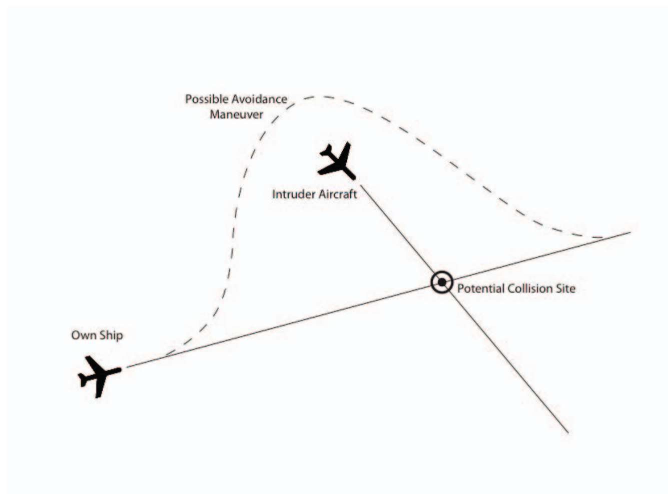

Fig. 2. Collision avoidance path enabled by radar sensor and UAS flight path planning algorithm.

The first step for collision avoidance as shown in Figure 2 is intruder position detection. Both range and bearing need to be known. FMCW radar is a good choice for detecting range to targets in UAS applications because continuous wave radar systems have a lower peak transmit power than pulsed radars [6]. To estimate the bearing of targets a monopulse configuration is used, requiring the radar to have two receive channels.

To reduce size, weight, and cost, the FMCW used a single MMIC transceiver chip (Viasat, Inc.). The MMIC is a 24 Ghz transceiver chip with two receive channels. The homodyne architecture provides intermediate frequency (IF) outputs for the two receive channels after mixing with the transmit chirp signal. The radar system required additional functional blocks integrated on an RF PCB, IF PCB, and digital board (see

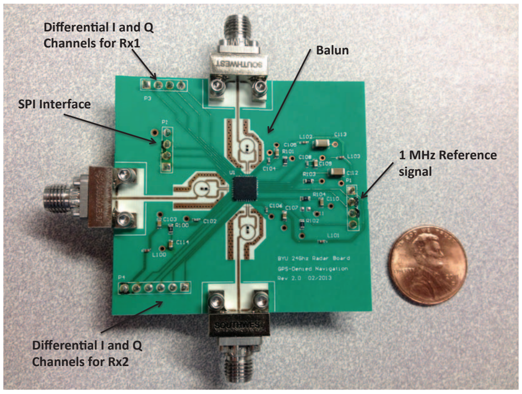

Fig. 3. Radar board with transceiver MMIC and RF signal chains.

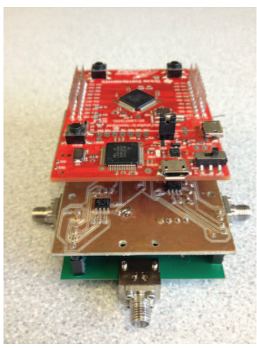

Fig. 4. Complete radar including the processor board (top), baseband board (middle), and radar board (bottom).

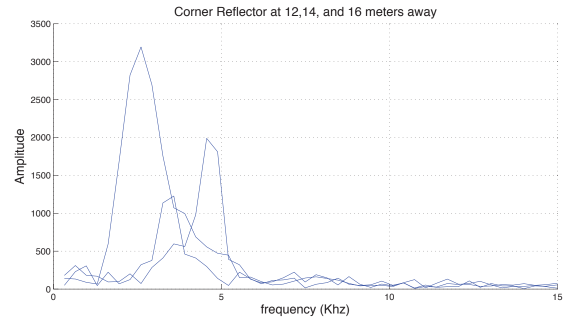

Fig. 5. Fourier transform of the radar output IF signal with a 1.5 ft corner reflector at various distances.

Figure 3):

- Serial peripheral interface for communicating with the radar chip
- Baluns to couple 100 Ohm differential RF transmit and receive lines
- Differential to single ended amplifier for IF signals
- 1 Mhz reference signal for chip phase-locked loop
- Analog to digital converter for sampling

The combined radar system is composed of three subsystems: radar, baseband, and processor. The radar board contains the MMIC transceiver chip as well as connectors for antennas (1 Tx, 2 Rx). The baseband layer combines differential signals output by the transceiver and includes a gain stage to level the output for analog to digital conversion and processing on a Stellaris microcontrollar board (TI, Inc.). Three 24 GHz planar microstrip antennas are used for the transmitter and two receiver channels. Pulse bandwidth and repetition frequency were designed to optimize the range resolution to the SAA application.

III. Radar Testing

Testing of the radar was done with both delay lines and corner reflectors. After attaching a delay line the IF signal output by the chip was read using an oscilloscope. The radar chirp used a sawtooth configuration with 140 MHz bandwidth and had a PRF of 730 Hz. The delay line was 6 meters long and produced the expected beat frequency of 3 kHz. Antennas were attached and the radar was tested outdoors with a corner reflector was moved various distances. As the corner reflector distance increased, so did the IF output of the radar, as shown in Figure 5.

IV. Conclusions

In this paper we have demonstrated the basic functionality of an FMCW radar sensor with mechanical and RF performance designed for UAS sense and avoid applications. Future work will involve integration of the radar and digital signal processing module onto the UAS. Autopilot and collision avoidance algorithms will then be tested as real time data is collected and processed. This work is an important step in enabling UAS to coexist in civil airspace with other manned and umnanned aircraft for a wide variety of commercial applications.

Acknowledgement

Funding for this research was provided by the NSF Industry/University Cooperative Center for Unmanned Air Systems (C-UAS).

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