

Development of a Passive Dual Channel Receiver at L-Band for the Detection of Drones

Benjamin Griffin[#], Alessio Balleri[#], Chris Baker^{*}, Mohammed Jahangir^{*} and Stephen Harman[†]

[#]Centre for Electronic Warfare, Information and Cyber, Cranfield University,
Defence Academy of the United Kingdom, Shrivenham, SN6 8LA

^{*}School of Engineering, University of Birmingham, Birmingham, B15 2TT, United Kingdom

[†]18-21, Evolution Business Park, Milton Rd, Impington, Cambridge CB24 9NG, United Kingdom

{b.griffin, a.balleri}@cranfield.ac.uk, {c.j.baker.1, ⁴m.jahangir}@bham.ac.uk, ⁵stephen.harman@aveillant.com

Abstract — Staring radars use a transmitting static wide-beam antenna and a directive digital array to form multiple simultaneous beams on receive. Because beams are fixed, the radar can employ long integration times to detect slow low-RCS targets, such as drones, which present a challenge to traditional air surveillance radar. The use of multiple spatially separated receivers cooperating with the staring transmitters in a multistatic network allows multi-perspective target acquisitions that can help mitigate interference and ultimately enhance the detection of drones and reduce estimation errors. Here, the development and experimental results of a passive, dual-channel, L-band receiver are presented. The receiver has been used to take measurements of both moving vehicles of drones in flight using a bistatic staring transmitter. An analysis of the receiver is presented using GPS is used to quantify the estimation performance of the receiver.

Keywords — Passive Radar, Multistatic Networks, Drones

I. INTRODUCTION

The robust detection of drones is an active area of research in the radar domain. Due to their small size, low flight profile and slow speed, drones present a unique challenge to traditional air surveillance radars. Studies into the use of radar networks are receiving increased interest as they have the potential to improve the detection of drones and drone-like targets [1]. A proposed list of capabilities for a radar system to be able to detect and track drones has been presented by Poitevin et al [2] and include:

- Sensitivity for very small detectable signatures
- Fast refresh rates
- Height measurement capability
- Large volumetric coverage requirements
- Nuisance elimination
- System cost

Staring array radars have been built that can detect small drones out to a range of 5 km and satisfy the sensitivity, fast refresh rate, and height measurement capability [3]. The combination of the staring array radar and a multistatic radar network can further improve the performance of a drone detection and tracking system. Small scale multistatic radar networks have successfully demonstrated an ability to detect and track drones; in particular, the NetRad and NeXtRAD radar [4] [5]. These are active multistatic radar networks operating in the S, L and X-band. These networks have also shown the capability to detect the micro-Doppler signature

of a drones rotors, which is a crucial part of improving the classification performance of a radar system [6] [7].

Passive radar systems are an attractive solution as they do not interfere with existing radar systems, and as such multiple systems have been built [8]. Small WiFi-based networks consisting of a single transmitter and two receivers have been studied by Milani et al [9]. While WiFi-based methods can be considered a green system and ideal for urban environments, they are limited in range. The use of Digital Terrestrial Multimedia Broadcast (DTMB) signals are better suited as the transmitters are generally mounted high up and have been shown to detect drones over greater distances [10].

This paper presents the design and results of experimental trials of a passive dual-channel receiver. The receiver is designed to cooperate with an Aveillant radar as part of a multistatic radar network. The Aveillant radar is a staring array radar operating in the L-band. Previous measurements from the Aveillant Gamekeeper radar have reported in-flight micro-Doppler signatures of both drones and birds [11]. The purpose of the network is to improve the detection of drones and reduce estimation/localisation errors. The cooperative network concept is based on the principles of passive radar but has the advantage that, unlike many passive systems, the transmitted waveform is designed to detect drones. The staring nature of the Aveillant radar also means that the passive receivers can record the reference signal without any form of pulse-chasing. An initial study into the optimal geometry of such a network has been previously explored as part of this project [12].

II. RECEIVER DESIGN

The networks receiver nodes are designed to operate in a multistatic configuration with a central Aveillant radar; therefore, each receiver contains two channels, a reference and a surveillance channel. Fig. 1 illustrates the cooperative network concept demonstrating how the use of a central staring radar enables the receiver nodes to continually record the reference signal, maximising dwell time and detection performance.

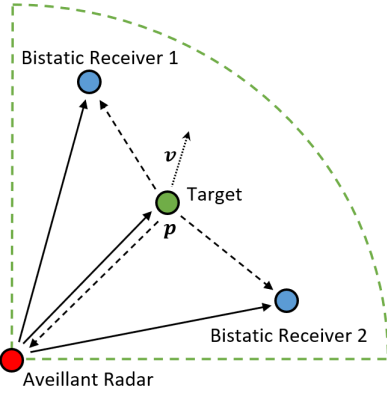


Fig. 1. Aveillant Gamekeeper Radar and Proposed Network Geometry

Each receiver in the network is connected to a GPS antenna, used to record the receiver position and the current time (UTC). The target drone also contains a GPS receiver used to record aspects of the drone's flight, such as its position, speed and heading. After a trial is complete, the use of the drone's GPS data helps to improve the correlation of the signals received across the network with the drone's position.

III. RECEIVER IMPLEMENTATION

The dual-channel receiver prototype consists of two receiving channels, a voltage-controlled oscillator (VCO) block, digitizer, GPS antenna and computer, as shown in Fig. 3 and Fig. 2. The VCO is an Aaren Technology Electronics RFF25611 component that generates the local oscillator (LO) signal. The LO signal is amplified by a Mini-circuit ZX60-P105LN+ and attenuated to 10dB. An RF splitter (Mini-circuit ZX10-2-20-S+) splits the LO signal into two signals at 7dB.

The received signal from each antenna is filtered by a bandpass filter and amplified by a low noise amplifier (Mini-circuit ZX60-P162LN+) to increase the signal power by 22dB. The amplified signal is mixed down with a Mini-circuit ZX10-2-20-S+ using the LO signal from the VCO block. The received signals, now at baseband, are filtered by a 45MHz low pass filter (Mini-circuit VLF-45+) and digitized using a TiePie Handyscope HS5 digital oscilloscope.

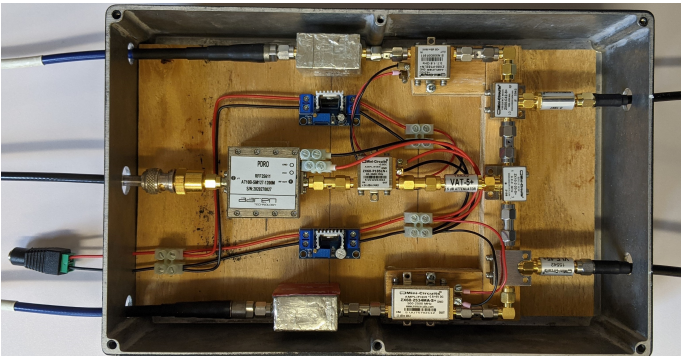


Fig. 2. Receiver Hardware

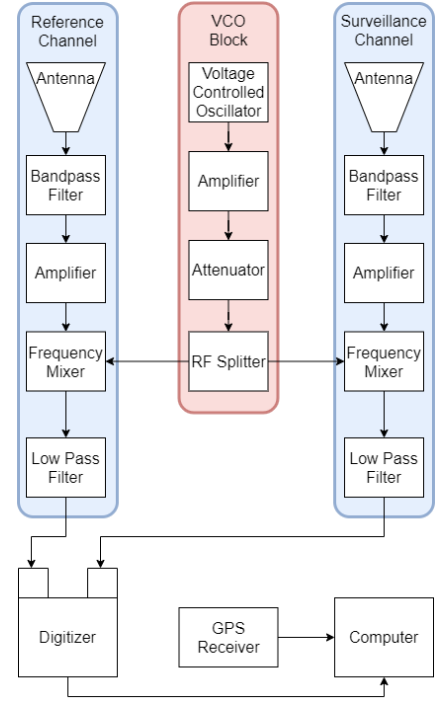


Fig. 3. Dual Channel Receiver Block Diagram

IV. SIGNAL PROCESSING

The radar operates in a block data collection cycle. The digitizer is set to record a continuous block of data from both channels when triggered. Once the digitizer finishes recording, the data is saved along with the timing and location data from the attached GPS, a GlobalSat BU-353-S4. The recorded data is processed offline after the measurements are complete. The data from both the reference channel and surveillance channel and the mean value from each channel is subtracted. The Hilbert transform generates the IQ components of the signal. The peak of the reference channel in the frequency domain centres a bandpass filter over both channels, which isolates the desired signal. The filtered signals are transformed back to the time domain, and each channel is divided into pulses to form two Fast-Time Slow-Time (FTST) matrices. The reference pulses are used to perform match filtering on the surveillance pulses. The short-time Fourier transform and the Range-Doppler map are then generated. Moving Target Indication (MTI) is performed on the Range-Doppler map to remove any stationary clutter and the direct transmitter to receiver signal.

V. MEASUREMENTS

Measurements of a moving car and drone in flight have been carried out to evaluate the receiver's performance at the Radar Laboratory of Cranfield University, at the Defence Academy of the UK in Shrivenham. An Anritsu MS2691A Signal generator connected to a horn antenna (A-Info, LB-OH-650-10) was used to generate a replica of the signal transmitted by the Aveillant Gamekeeper radar at 0dBm.

Measurements were obtained by recording continuous blocks of 250ms of data from each channel, sampled at 20MHz (5M total samples). The frequency of the LO signal was tuned to centre the received signal after down-conversion at 3 MHz.

A. Measurements of a Moving Car

Measurements of a moving car were taken using the dual channel receiver acting as a bistatic receiver to a separate transmitter, with a baseline of 10m. In the measurements the car was driven towards and away from the receiver.

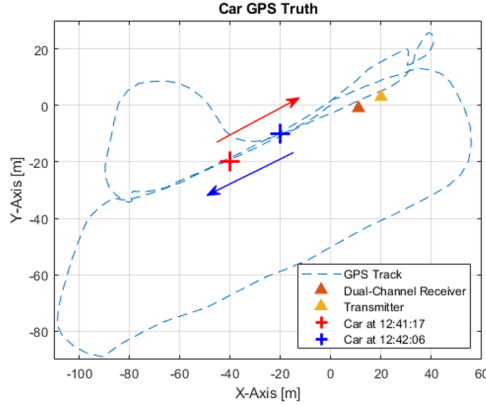


Fig. 4. Car GPS Truth

Fig. 4 shows the GPS track of the car as well as the positions of the dual channel receiver and transmitter. The car was driven towards and away from the receiver at constant speeds. The two markers indicate the position of the car at 12:41:17 and 12:42:06, the range-velocity maps at these times are shown in Fig. 5 and Fig. 6.

In Fig. 5 the target is detected with an SNR of 49dB at a range of 46m with a velocity of 5.4 m/s. The GPS recorded the car at a range of 50m with a velocity of 6.6m/s. In Fig.6 the target is detected with an SNR of 52 dB at a range of 22.5m with a velocity of -5 m/s. The GPS recorded the car at range of 32 m with a velocity of -5.2 m/s.

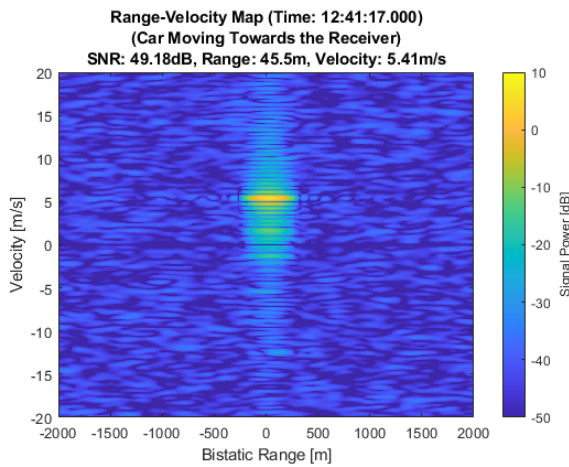


Fig. 5. Range-Velocity Map of a Car Moving Towards the Receiver

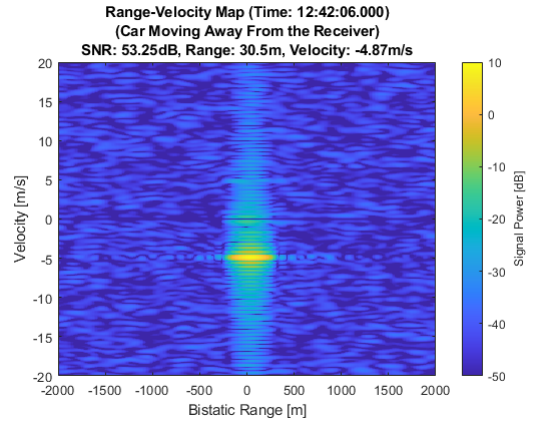


Fig. 6. Range-Doppler Map of the car driving away from the receiver

The radar reports the difference in SNR between the two measurements as 4dB. Theoretically, the difference in SNR should be 7dB based on the differences in range. This apparent loss of 3dB is most likely due to a combination of GPS localisation errors and the VCO losing coherency. The relatively long 250ms integration time could result in non-coherent integration and a decrease in SNR.

B. Measurements of DJI Matrice 600 Pro

The DJI Matrice 600 Pro is a hexacopter drone measuring 1.6m by 1.5m. For these measurements, the low noise amplifier on the reference channel was changed (Mini-Circuit ZX60-2534MA-S+) to increase the received signal power.

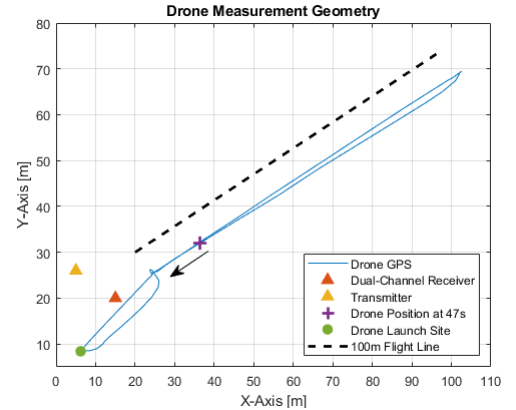


Fig. 7. Drone Measurement Geometry

During the measurement, the drone took off and hovered in front of the receiver at a height of 5m, then flew 100m away from the receiver maintaining the 5m altitude before turning and flying back. Fig.7 illustrates the relative positions of the transmitter and receiver with respect to the trajectory of the drone, as recorded by the onboard GPS. Fig. 8 shows the relative range and Doppler shift of the drone overlaid with the detections from the receiver. The dotted lines indicate the period of time when the target is in front of the receiver. The receiver takes approximately 3s to record one block of data; therefore, the number of possible detections is limited to a maximum of 12 over the 35s interval that the drone is visible.

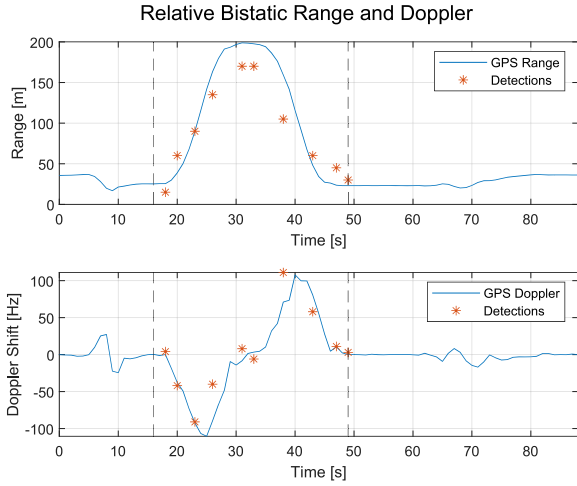


Fig. 8. Relative Range and Doppler and Radar Detections

A detection SNR threshold of 25dB was used to avoid detecting the substantial interference around zero. The interference to noise ratio is approximately 20dB. The range measurements have an average error of 22m with a root mean square error of 13m, while the Doppler measurement has an average error of 14Hz with a root mean square error of 16Hz, compared to the GPS trajectory.

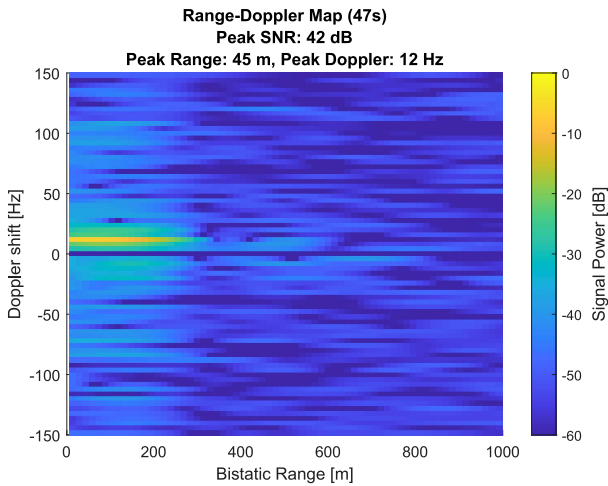


Fig. 9. Range Doppler Map recorded 47s into measurement

Fig. 9 shows the Range-Doppler Map recorded 47s into the measurement. The drone is detected at a range of 45m, Doppler shift of 12Hz at SNR of 42dB. The onboard GPS states the target is at a bistatic range of 32m, with a Doppler shift of 12Hz.

VI. CONCLUSION

This paper presents measurements of a car and a drone in flight taken using a passive dual-channel receiver. The results demonstrate that the receiver is capable of detecting and tracking a drone in flight. The detections from the receiver are further shown to be in general agreement with the drones onboard GPS.

Further work is required to improve the receiver, particularly the VCO, as it is not maintaining coherence for the full integration time. Replacement of the VCO with a phase-locked oscillator would improve the length coherent integration time, increasing the overall SNR.

The future aim of the project is to deploy multiple passive receivers in a cooperative multistatic network in conjunction with the Aveillant radar. It is envisioned that the increased transmission power will allow the measurement of targets at greater ranges.

ACKNOWLEDGEMENTS

The authors thank Thales Aveillant Ltd and Cranfield Defence and Security for funding this work under the Cranfield University 50:50 Industrial PhD scheme. The authors would also like to thank Janko Scepanovic for his initial work on the design.

REFERENCES

- [1] H. Griffiths, "Developments in bistatic and networked radar," *Proc. 2011 IEEE CIE Int. Conf. Radar, RADAR 2011*, vol. 1, pp. 10–13, 2011.
- [2] P. Poitevin, M. Pelletier, and P. Lamontagne, "Challenges in detecting UAS with radar," in *Proc. - Int. Carnahan Conf. Secur. Technol.*, vol. 2017-Octob. IEEE, oct 2017, pp. 1–6.
- [3] M. Jahangir and C. Baker, "Persistence surveillance of difficult to detect micro-drones with L-band 3-D holographic radar™," in *2016 CIE Int. Conf. Radar, RADAR 2016*. IEEE, oct 2017, pp. 1–5.
- [4] F. Hoffmann, M. Ritchie, F. Fioranelli, A. Charlish, and H. Griffiths, "Micro-Doppler based detection and tracking of UAVs with multistatic radar," *2016 IEEE Radar Conf. RadarConf 2016*, pp. 1–6, 2016.
- [5] R. Palama, F. Fioranelli, M. Ritchie, M. R. Inggs, S. Lewis, and H. Griffiths, "Measurements of Multistatic XL Band Radar Signatures of UAVS," in *2019 Int. Radar Conf. RADAR 2019*. IEEE, sep 2019, pp. 1–5.
- [6] F. Fioranelli, M. Ritchie, H. Griffiths, and H. Borrión, "Classification of loaded/unloaded microdrones using multistatic radar," *Electron. Lett.*, vol. 51, no. 22, pp. 1813–1815, 2015.
- [7] M. Ritchie, F. Fioranelli, H. Griffiths, and B. Torvik, "Monostatic and bistatic radar measurements of birds and micro-drone," in *2016 IEEE Radar Conf. RadarConf 2016*. IEEE, may 2016, pp. 1–5.
- [8] M. P. Jarabo-Amores, D. Mata-Moya, P. J. Gomez-Del-Hoyo, J. L. Barcena-Humanes, J. Rosado-Sanz, N. Rey-Maestre, and M. Rosa-Zurera, "Drone detection feasibility with passive radars," in *2018 15th Eur. Radar Conf. EuRAD 2018*. IEEE, sep 2018, pp. 313–316.
- [9] I. Milani, F. Colone, C. Bongioanni, and P. Lombardo, "WiFi emission-based vs passive radar localization of human targets," in *2018 IEEE Radar Conf. RadarConf 2018*. IEEE, apr 2018, pp. 1311–1316.
- [10] G. Fang, J. Yi, X. Wan, Y. Liu, and H. Ke, "Experimental Research of Multistatic Passive Radar with a Single Antenna for Drone Detection," *IEEE Access*, vol. 6, pp. 33 542–33 551, 2018.
- [11] M. Jahangir and C. J. Baker, "Extended dwell Doppler characteristics of birds and micro-UAS at l-band," in *Proc. Int. Radar Symp.* IEEE, jun 2017, pp. 1–10.
- [12] B. Griffin, A. Balleri, C. Baker, and M. Jahangir, "Optimal receiver placement in staring cooperative radar networks for detection of drones," in *IEEE Natl. Radar Conf. - Proc.*, vol. 2020-Sept. IEEE, sep 2020, pp. 1–6.



DSPACE

<https://dspace.org/>

Development of a passive dual channel receiver at L-band for the detection of drones

Griffin, Benjamin; Balleri, Alessio; Baker, Chris J.; Jahangir, Mohammed; Harman, Stephen

2022-06-02

Institute of Electrical and Electronics Engineers (IEEE)

<https://doi.org/10.23919/EuRAD50154.2022.9784465>

Griffin B, Balleri A, Baker C, et al., (2022) Development of a passive dual channel receiver at L-band for the detection of drones. In: 18th European Radar Conference (EuRAD) 2021, 5-7 April 2022, London UK