# UAV Detection in Millimetre Wave Radar Bands

Stephan STANKO; Winfried JOHANNES; Michael CARIS
53343 Wachtberg
GERMANY

Stephan.stanko@fhr.fraunhofer.de

***ABSTRACT***

*UAV detection is getting more and more important. Especially because of intrinsic illumination, radar is a technique to be highly considered for this purpose. There are different aspects to be discussed therefore: design and operation of the used radars, the used signal processing including micro-doppler as well as the modelling of the UAV's signature.*

## 1.0 INTRODUCTION

Surveillance of many military and civil infrastructures to detect and track potential threatening targets on ground or in the air is still a very important capability of sensor systems. The targets to be detected may be suicide attackers or drones, which are to be used for spying, smuggling or acts of terrorism.

The detection of these objects can be divided into two different types of problems: First the choice of the systems and the used processing, second the modelling of signature of the tracked object including the signature's change while operation of the object.

## 2.0 SYSTEM DESIGN, USED WAVELENGTH AND PROCESSING

Detection of UAVs independent of weather, day and night as well as challenging environments is best done using radar technique. Especially in urban environment and with distances of several hundreds of meters, the usage of millimetre-wave and sub-millimetre-wave systems is optimal. So, multi-reflections are cancelled out by physical effects of the rough surface that is important between buildings surrounded by asphalt. Additionally, the Micro-Doppler of the minimal movements (e.g. vibrations) of the UAVs leads to an easily measurable frequency spectrum, which is typical for certain drones.Surveillance of many military and civil infrastructures to detect and track potential threatening targets on ground or in the air is still a very important capability of sensor systems. The targets to be detected may be suicide attackers or drones, which are to be used for spying, smuggling or acts of terrorism.

### 2.1 System design

There are several types of systems for a 360 degree perimeter detection. Either the system uses a rotating single channel sensor or a combination of multiple systems looking in different directions is used. Both types of systems have advantages and disadvantages. When thinking about Doppler measurements one has to consider, the internal movement of the system.

Besides optical systems, modern millimetre-wave radar sensors working at the frequencies around 35 GHz, 94 GHz, 210 GHz, or 300 GHz can be used for such applications, because they can do image-based monitoring of an area of interest independent of weather and daylight. Furthermore, measurements through dust and fog are possible. These operating frequencies are chosen because of a minimum of atmospheric attenuation in this band and very compact and lightweight radar sensors can be realized with high signal bandwidth to achieve fine range resolution. The very small wavelength of these radar systems leads to very high sensitivity to small structures of the background or the target, to very fine velocity resolution and specific materials can be penetrated to detect hidden dangerous objects [1]. Additionally, such millimetre wave radar systems have low power consumption and are characterized through a better target-to-background ratio than classical radar bands. Because of the very high frequency, the antenna size together with the aperture angle is small and the antenna gain is high. Furthermore, stand-off detection of dangerous materials like explosives and signature analysis of Doppler or radar cross section of targets is possible. The radar itself was designed by the Fraunhofer Institute for High Frequency Physics and Radar Techniques (FHR) and the main radar components [2] were developed by the Fraunhofer Institute for Applied Solid State Physics (IAF) located in Freiburg.

**Figure 2-1: Photograph of the radar front-end and the camera.**

## 2.2 Processing

The system is able to measure the range by means of FMCW frequency measurement, the radar cross section RCS via the reflected energy corrected by the range as well as azimuth, which is measured by rotating the radar front-end. Additionally, the target's velocity can be calculated from the Doppler effect. In case of the used FMCW radar a cross-range Fourier transformation is applied. For example, using 42 chirps of the radar system a velocity resolution of 0.7 m/s can be achieved. Thereby, it is possible to distinguish between different kinds of targets by analysis of the velocity spread. This means, that different kinds of targets can have several detections in the Doppler spectrum. For example, a point target with no internal movements (e.g. vibrations) has only a few number of detections in the Doppler spectrum. In contrast, targets with a lot of different moving parts exhibit more detections in the Doppler spectrum. This is displayed exemplarily in Fig. 2-2.

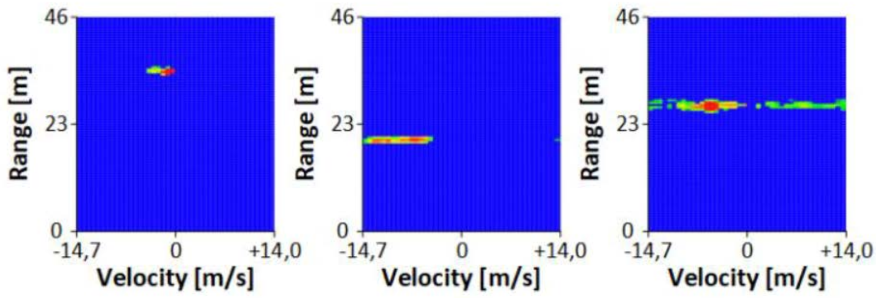


**Figure 2-2: Range-velocity diagram of three different targets. Left: Walking human, middle: flying bird, right: flying UAV.**

There is even the potential of the system to estimate the height of the system, which means to measure the elevation angle to the target [3].

## 3.0 MEASUREMENT OF THE TARGETS SIGNATURE

Measurement has been done in laboratory as well as in field. Laboratory measurements are mostly static, but give a very detailed information about the RCS of the object.

Static measurements in the anechoic chamber can be performed starting at 10 GHz up to more than 300 GHz. In addition, the RCS of the objects is evaluated in the field via turntable measurements in a distance of about 140 m. These measurements are quasi static, in addition the motor of the vehicle may be started, so vibrations are included into these measurements. The most challenging but also most promising evaluation of the RCS is using a radar pointing to a flying drone. These measurements are also performed, at the time being, the correlation between the radar data and INS data from the drone are taking place.

One Measurement was performed using a network analyser, looking to the UAV in different aspect angles. The measurements were situated in an anechoic chamber.

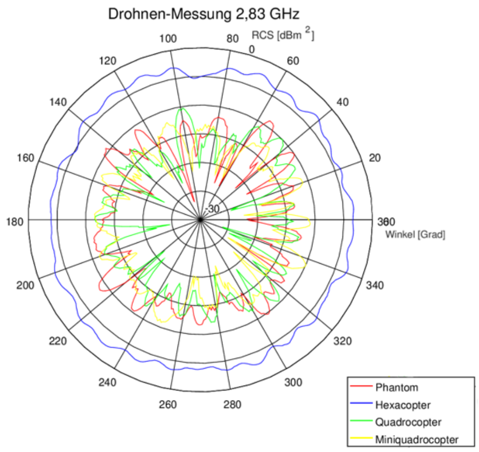


**Figure 3-1: RCS in dBm$^2$ of four typical UAVS at a center frequency of 2.8 GHz.**

Fig. 3-1 shows a typical measurement. An overall result shows, that at a Frequency around 2.8 GHz an average RCS of $\sigma = -15\ dBm^2$ is to be expected.

High resolution measurements of the targets can also be performed using the inverse SAR method (ISAR). A turntable configuration is used as shown in Fig. 3-2.

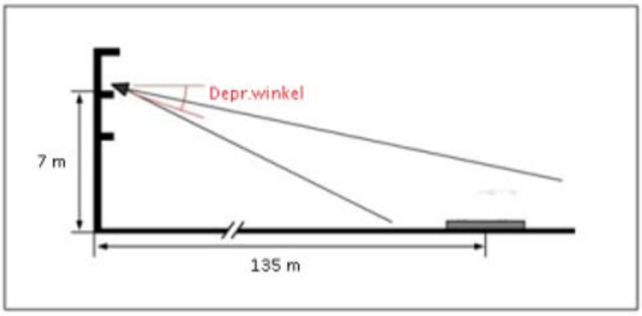


**Figure 3-2: Turntable configuration for measurement of the UAV**

The turntable rotates with highly stable velocity while performing the measurements. The position is transmitted to the Radar back-end in real time, so each measurement chirp can be correlated with an angle information. So after the measurement a two dimensional high resolution image can be processed.

The measurements were done for two different UAV types (F450 and F550) and four different Radar frequencies were used (10 GHz, 35 GHz, 94 GHz and 210 GHz). The resolution depends on the used frequency and is below 4 cm.

Fig. 3-3 shows the ISAR images of the two different UAVs.
One can clearly see the different configuration of the arms and rotors. , Especially the support structure for the motors and the motors themselves are clearly visible. Although the resolution of the system would be fine enough, no rotors can be seen in static configuration. These images are under future examination.

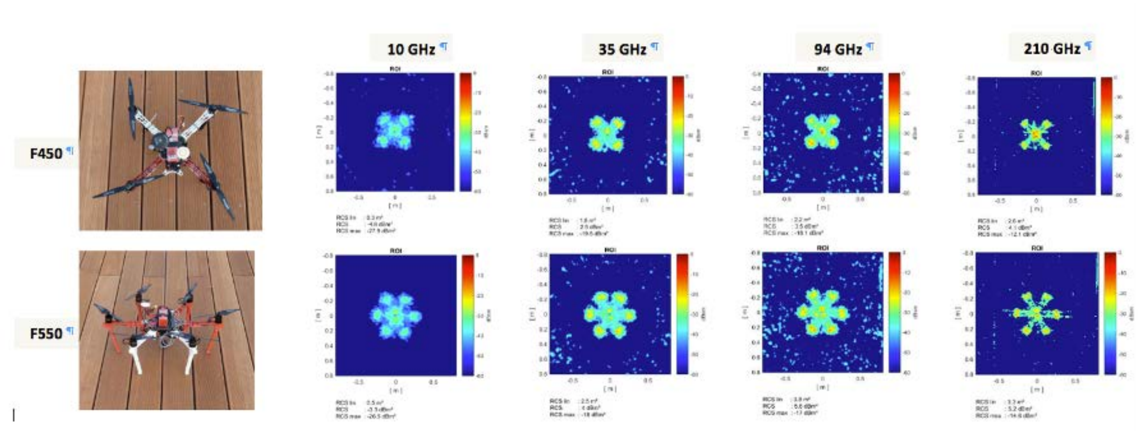


**Figure 3-3: ISAR images of the F450 and F550 UAV at Frequencies 10 GHz, 35 GHz, 94 GHz and 210 GHz**

## 4.0 CONCLUSION

This abstract describes the system design and implementation of a drone measurement radar. In addition, it shows measurements of the RCS and the Doppler effect based on the intrinsic movement flying drone.

### 4.1 Ackknowledgements

Part of this work was funded by WTD52, WTD81 and Bundesministerium der Verteidigung

## 5.0 REFERENCES

[1] M.Caris, W.Johannes, S.Stanko, N.Pohl, “Millimeter Wave Radar for Perimeter Surveillance and Detection of MAVs (Micro Aerial Vehicles)”, Proceedings IRS 2015, Dresden (Germany), pp284-287, June 2015.

[2] I. Kallfass, A. Tessmann, H. Massler, U. Lewark, M. Kuri, M. Riessle, M. Zink, and A. Luther, “Balanced Active Frequency Multipliers for W-Band Signal Sources”, Proc. EuMIC 2011, Manchester (UK) , pp. 101-104, October 2011.

[3] W. Johannes, M. Caris, S. Stanko, “94 GHz Radar used for Perimeter Surveillance with wide Target Clarification”, 21st International Radar Symposium (IRS), Proceedings 2020

## 6.0 BIOGRAPHY

Dr. Stephan Stanko, received Diploma in Physics 1998 and Dr.-rer.-nat. in 2002 at University of Cologne. He worked in the field of system development for radio astronomy and since 2007 he is with the FHR. He is specialised in millimetre-wave radar and is now head of the department high-frequency radar and applications.