# Radar-Assisted Relative Location of Multiple Targets and Collaborative Sharing of Location Information Between Multiple Radars

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***ABSTRACT***

*This paper presents the application of small FMCW radars operating in mmWave spectrum range for determination of relative location of multiple targets without drift over time. Static reference points are used to translate target relative speed, distance, and location to absolute location. Additionally, using of the multiple sensors on the same platform and sharing of location data between multiple radars and multiple platforms results in improved accuracy of absolute positioning and reduces location drift.*

***Index Terms -*** *FMCW radars, mmWave spectrum range, improved accuracy of absolute positioning*

## 1.0 INTRODUCTION

New advances in the mmWave radar development and miniaturization have enabled applications of the radars in multiple applications not possible before, from automotive adaptive cruise control and even autonomous driving but also multiple applications in industry not so common for radar applications. The main advantages of the small mmWave radars are ability to measure distance and speed very precise in almost all conditions and with added digital beamforming or interferometric measurements of angle, it is also possible to measure precise angle of the targets, [1]. Frequency range in K band (24 GHz) or W band (80 GHz) enables miniaturization of the radars due to the very small antennas and using FMCW principle transmitter power of the radar is much smaller for the comparable performances to other non-continues waveform principles. Frequency range in mmWave bands, especially W band enable high bandwidth that is required for the precision in the distance measurement. Such small radars with low transmitter power working in ISM bands with low power consumption can be used in multiple platforms, commonly in UGV and UAV but not limited, and such devices are giving precise measurements without drift over the time.

Example of sensor used for precise speed measurement in small form factor with low power consumption is CW Dopper radar like Geolux RSS-2-300W working in K band with 100 mW transmitter power that can measure speed in the range from 0,02 m/s to 15 m/s with resolution 0,001 m/s, [2]. The radar is commonly used in industrial, environmental and hydrology applications for very precise speed measurements but also in the aviation for the measurement of the vertical speed of the airplane. Aviation application is great example of sensor fusion where radar is used for vertical speed measurement of the airplane for the first 300 m of the altitude in the climb and even more important for the last 300 m of the descent on the approach and landing. Radar vertical speed measurement based on Doppler principle is not significantly affected by atmospherically conditions, ground topology below the airplane and has great resolution and drift characteristics with basically no drift at all. The additional advantage is that radar can measure speed with regular sample rate up to 10 Hz and very small latency. When combined with barometric altitude and vertical speed measurement quite common in all aircrafts today, standard radar altimeters, and with inertial navigation also very common in modern aircrafts, into the sensor fusion it is possible to enhance overall navigation solution quality and reliability. Speed measurement resolution of 0,001 m/s (1 mm/s) is very hard achievable with other measurement methods, and it is perfectly suitable for precise landing systems especially in final landing phases during the flare maneuver where low vertical speed is expected and small changes in the speed and low latency in measurement will make difference between great and the hard landing both for the HTOL and VTOL platform.

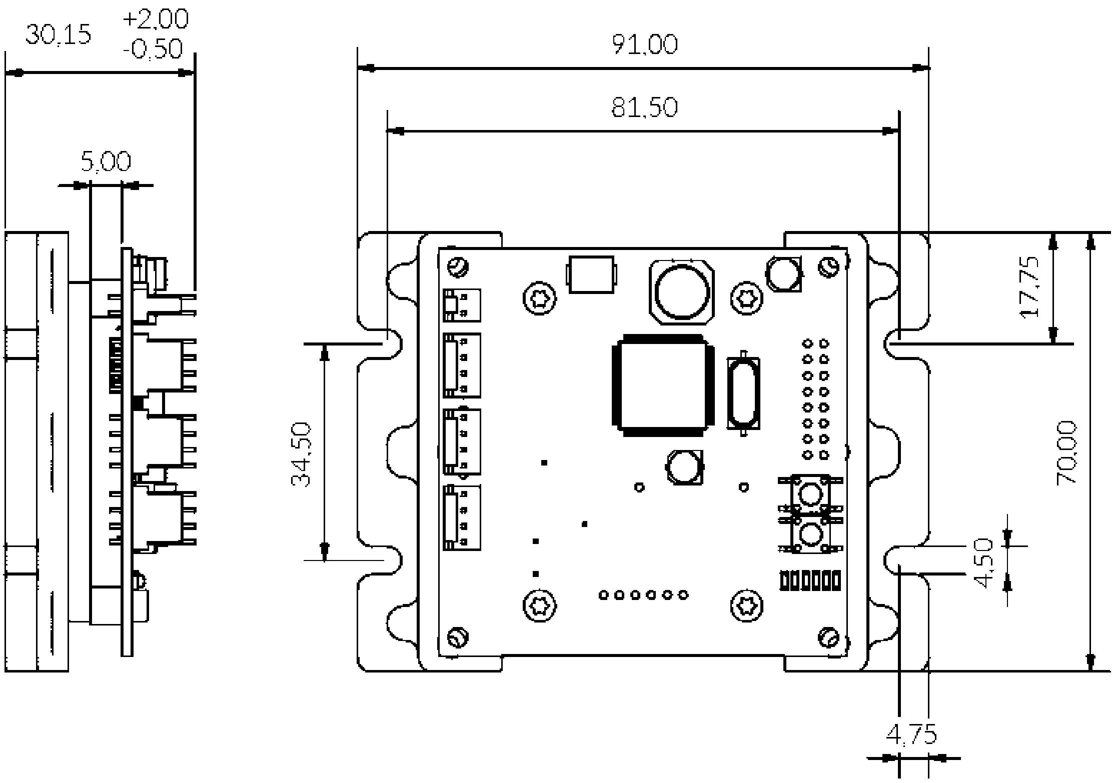


**Figure 1-1: OEM high accuracy Doppler radar module**

The small size, low weight and very low power consumption of such sensor makes it perfect for the UAV platforms where size and weight are critical. Moreover, combining three or more sensors pointing in different angles it is possible to measure vector speed of the platform to get relative movement speed of the platform in relation to the ground in all 3 axes.

The main disadvantage of CW Doppler only radar is inability to measure distance of the target. There are several ways in solving of this problem but in recent time the most popular is FMCW where CW radar transmit wave is frequency modulated usually by linear frequency change. The mmWave FMCW radars are today commonly used in very large portfolio of applications from traditional security and defense long range radars to special industrial instruments for special measurement and location applications. Special case of very useful radars in location and navigation are mmWave radars in W band where 4 GHz bandwidth is available in ISM band from 77 GHz up to 81 GHz without requirements for the special permit in most parts of the world, [3]. As for the FMCW radars overall bandwidth is determining the resolution in W band today it is possible to make sub millimeter resolution radars in reasonable distance measurement range of around 50 m and using of interferometry in multi antenna systems it can be even reduced in to the μm range. W band operation has additional advantage in very small antenna size and overall radar dimension.

## 2.0 FMCW K-BAND MULTIPLE RADAR LOCATION DEMO

Location of the objects in the complex urban environment with small and low power SDR based radars has been demonstrated as the part of the work in SET-229 NATO STO workgroup during the demo in Sennybridge, UK on 16 August 2019. Total three radars have been used in the demo covering the area of interest with time synchronization and data sharing for accuracy improvement. Radars are based on the SDR platform utilizing FPGA SoC combining multicore ARM v9 processor with FPGA field accessible with high-bandwidth data bus from the CPUs. The microwave transceiver was implemented as the MIMO patch phased array antenna system utilizing 8 receiver antennas with independent receiver channels and 5 transmitter channels with linear frequency modulation and very low phase noise generator. Operating frequency band was 24,05 GHz to 24,175 GHz with output power (EIRP) limited to 100 mW to comply with EN 300 440 v2.1.1 regulation.

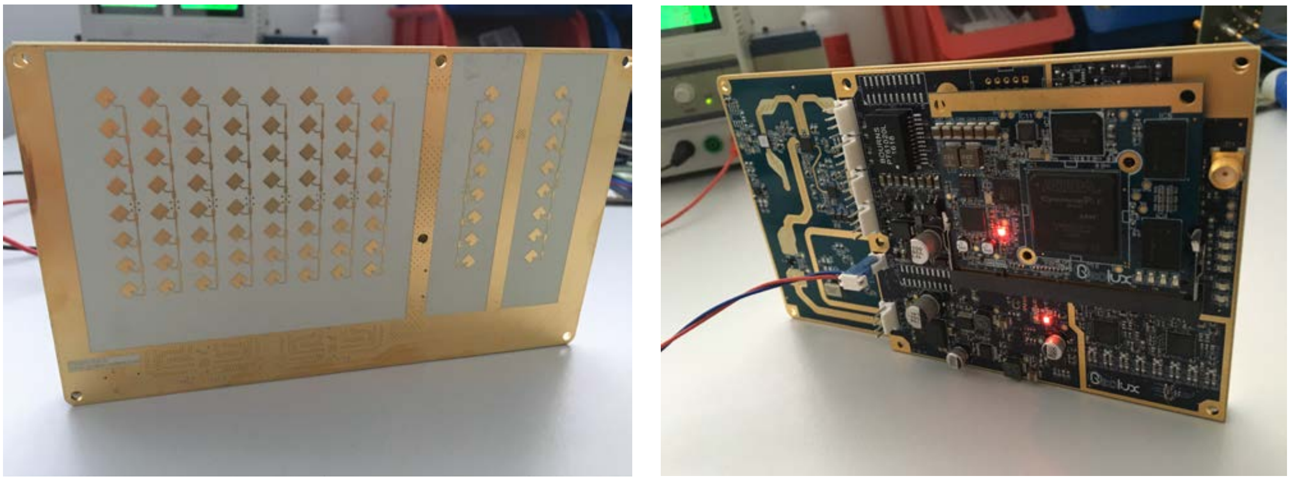

**Figure 2-1: FMCW radar electronics design**

Radars use in the demonstration can scan the area with 90° field of view in the horizontal plane and 24° field of view in the vertical plane. The location resolution and achievable accuracy can be configured in the software and in the Sennybridge demonstration it was used ±0,5 m range accuracy with ±1° angle accuracy configuration. The scanning rate for the chosen configuration was 6 Hz. Maximal range of the radar was configured to 150 m and additionally limited in the software to fit borders of the area of interest and to avoid any unwanted detections outside of the area. Doppler speed resolution was configured to ±0,15 m/s with maximal speed before the overflow 12 m/s expected to cover the application with sufficient margin.

Radars have been enclosed in the standard Geolux RSS-4 radar machined aluminium IP68 enclosure with dimensions 210 x 130 x 30 mm and power consumption less than 10 W making it suitable for easy deploying and operation in the areas with no constant power supply. Processing power of the radar was sufficient to track 32 targets simultaneously, [4].

The radars were connected to the Mission C2 Center using wireless communications – standard WiFi was used during this demonstration, but the system could have easily used any standard tactical radio network with support for a standard Ethernet connection or serial RS232 or RS485 communication channel, [5].

Geolocation and time synchronization of the radar can be acquired using the onboard GNSS receiver but as during the demonstration GNSS signal was denied with jamming the geolocation was acquired manually with the help of the location map and drone footage and timing synchronization was implemented with radio link implemented in cooperation with USA partners.

In the Mission C2 Center mission control software was used to visualize data from all three radars installed in the demonstration. As radars R1 and R2 have been facing in the direction of each other and the coverage area was significantly overlaying the data sharing was used to enhance accuracy of the detection and the tracking.

**Figure 2-2: Radar installation for the SET-229 demonstration [5]**

During the demonstration radars have been mounted on to the tripod poles easily movable and easy to deploy and power supply was implemented using the battery pack for each radar. Small battery pack with 12V 7Ah battery was sufficient for the radar operation during the whole full day demonstration due to the low power consumption of the device.


**Figure 2-3: Map view in the Mission C2 Center [5]**

Geolux Orford modular Geographic Information System (GIS) platform was used to visualize the detection and tracking of the targets detected by radars, but it was also used to track movements of the targets by other systems that were presented in the demonstration by other participants. Area map was generated by overfly of the UAV with high resolution camera and the high-resolution Geo TIFF map was created that was easily imported to the Orford system and overlayed on the lower resolution satellite map covering wider area. Orford feature to select the best resolution map of the area was used for simple overly of the multiple maps.

Target tracking of each system in was shown by different marker on the map so it was possible to assess overlapping, drift and compare accuracy of all systems. The indoor tracking was also covered by the systems presented from partners from Turkey and UK and visualization of the tracking was shown on the map also. For indoor tracking interiors of some buildings in the area were mapped using a positioning and mapping system developed by Swedish partners and the 2D map was overlayed over the areal view of the buildings in Orford software.

## 3.0 RESULTS

The main objective for the demonstration was to demonstrate target tracking in the GNSS denied environment by several different system and ability to share location and cooperatively improve the location accuracy.

Advantage of the radars is ability to detect moving and static targets, scan the area with electronic scanning array antenna and there is no drift over the time in the measurement. Using low phase noise transmitters and FPGA accelerators to enable small size radars to process enough data it is possible to achieve cm resolutions and accuracy of the distance measurement and ±0,5° angle resolution or better. The main limiting factor for radars used in the demonstration to get better range resolution is limited bandwidth available in K band to stay compliant with EN 300 440 v2.1.1 where license free frequency band is limited to 24,05 GHz to 24,245 GHz. The maximal range is also limited by EN 300 440 v2.1.1 with EIRP limited to 100 mW that is sufficient for approximately 300 m maximal tracking range for the single walking human (RCS ≈0,75 $m^2$). The angle resolution in demonstrated radars is limited by the number of RX and TX antennas and accuracy of phase shifters but also with the available processing power in the system. The current configuration of the radar with ±0,5° angle resolution is the compromise between product price, size, and power consumption.


**Figure 3-1: Visualization of the tracking in the Mission C2 Center [5]**

Expected accuracy and tracking reliability was proven in the demonstration and very good false alarm ratio was also demonstrated with only few false detections in the very rough weather conditions and very complex urban like environment with quite a lot of vegetation and wildlife in and around the perimeter. Weather conditions have been constantly changing during the demonstration with heavy showers and high winds following sunny periods. No significant impact of the weather was observed on to the radar detection and tracking ability and accuracy.

Speed tracking in the radar was implemented by direct measurement using the Doppler effect combined with tracking algorithm that is combining measured speed with the speed calculated from the target movement. This model gives very precise speed measurement in wider range of target speeds and enables radar to compensate for the angle between radar and target trajectory affecting Doppler speed measurement. Demonstrated average speed accuracy was ±0,25 m/s with lowest accuracy for radial target trajectories as expected.

During the demonstration scenario with fixed radars and moving targets have been demonstrated but the RSS-4 radar can be very easily used on the moving platforms also. As the radar is implemented based on SDR platform only the change of the software in the background suppression algorithms and in the tracking, algorithm is required.

The future work is planned to increase range resolution with development of the new radar platform in W band (77 – 81 GHz), [3]. This platform will enable ranging accuracy in mm range or better. Using the active scanning array antenna and sufficient processing power this radar should be able to map the space around the radar with very high accuracy and enable navigation in such mapped space more accurate.

Additional advantage of the W band radar is much smaller antenna array and possibility to design more complex phased arrays with better characteristics in the smaller size. Also, dielectric lenses are easier to design, manufacture and fit in the package due to the much smaller wavelength and consequently smaller lenses sizes.

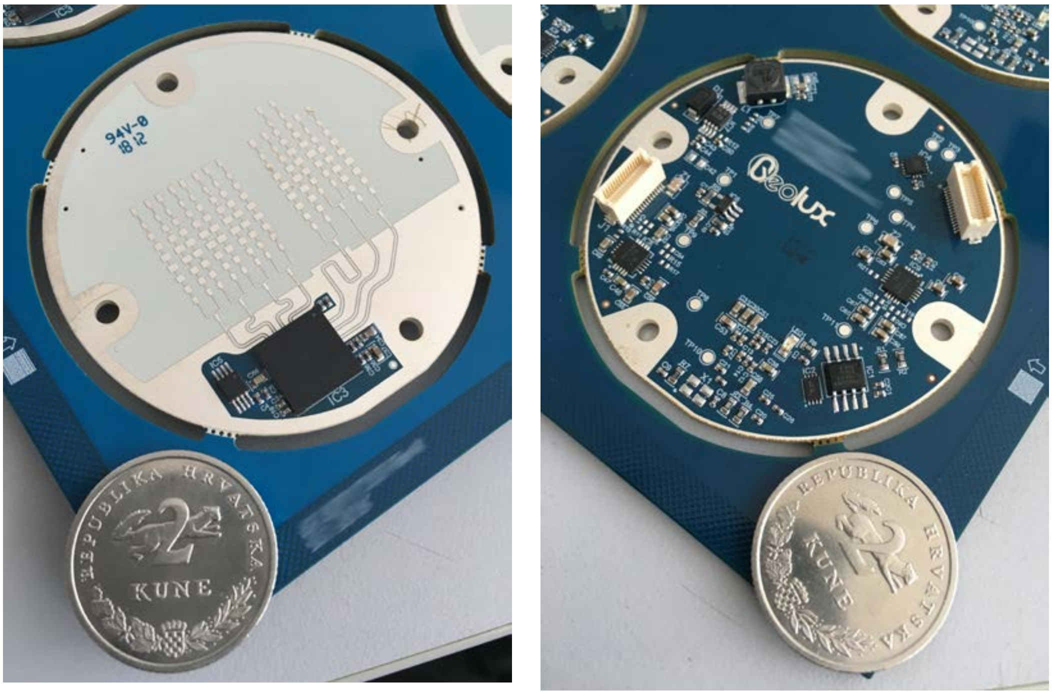


**Figure 3-2: W band radar microwave module [3]**

Such small size radars are ideal for the UGV, and UAV platforms and software defined radio platform enables various specific applications to be developed. Using advanced FMCW signal processing and combining it with AI detectors and object classification algorithms it is possible to use such radar for sub mm location and navigation relative to the surrounding objects.

## 4.0 CONCLUSION

Demonstration has proven that it is possible to use small radars for local space navigation and targets tracking and it is possible to achieve very good accuracy in the range of ±0,5m without drift over time. Even that the static ground mounted radars have been used in the demonstration small size and software defined architecture enables radars to be used on fixed applications but also on the moving platforms.

The main advantage of small microwave radars is ability to measure distances and speed very precise without drift over the time. Additionally with electronic beam steering technology it is possible to scan the space very fast and to create very precise maps that can be used for UGV and UAV local navigation. Advantage of the radars is also in the relatively small impact of the atmospheric conditions to the radar operation, allowing much better performance in rainy or fogy conditions than visual or LIDAR systems.

## REFERENCE

[1] S. Björklund, Signal Processing for Radar with Array Antennas and for Radar with Micro-Doppler Measurements, Blekinge Institute of Technology, Faculty of Engineering, Department of Mathematics and Natural Sciences. Swedish Defence Research Agency (FOI ), 2017, ORCID iD: 0000-0003-0701-706X

[2] RSS-2-300 Doppler Speed Radar User Manual,

https://drive.google.com/uc?export=download&id=0B2z_gLPsmBoCak1fV2JiVWhuZEE

[3] LX80 Non-Contact Level Meter User Manual,

https://geolux.ams3.cdn.digitaloceanspaces.com/documents/User%20Manual%20-%20LX-80.pdf

[4] RSS-4 Ground Surveillance Radar User Manual

[5] STO-TR-SET-229 Cooperative Navigation in GNSS Degraded / Denied Environments, STO technical report