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Multi Band Passive Forward Scatter Radar

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Outline

- Multi-Band Passive Forward Scatter Target Doppler Signature Extraction
- Measurements
  - Topology
  - Airliner trials
  - Light and ultralight aircraft trials
- Example -Velocity Estimation

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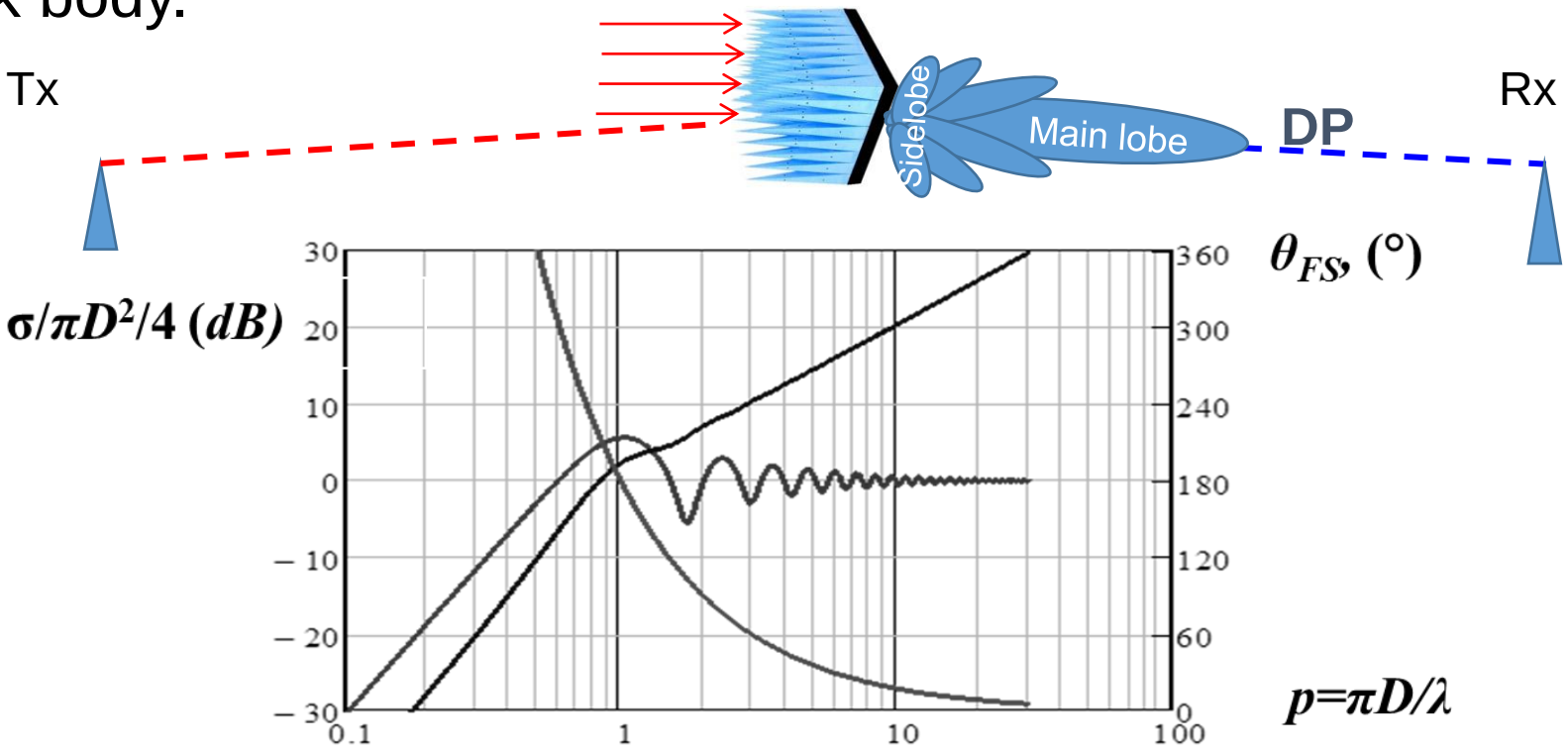
Forward Scatter Radar

FSR operates that way that a target reduces (shadowing) the level of a direct path (DP) signal even if the target is a black body.



$$\sigma_{FSCSMax} = 4\pi A^2 / \lambda^2$$

What for?

This is a part of ongoing study

- To check how the signal modulation influence on a signal processing. Full majority of published results based on dedicated waveforms usually non modulated CW.
- To collect data simultaneously for different frequencies' and frequency bands. Not only considering passive FSR but potentially active
- To understand which extra information we can extract from this nearly coherently processing the multi channel data flow
- Expectation: essential improvement in automatic targets classification and tracking

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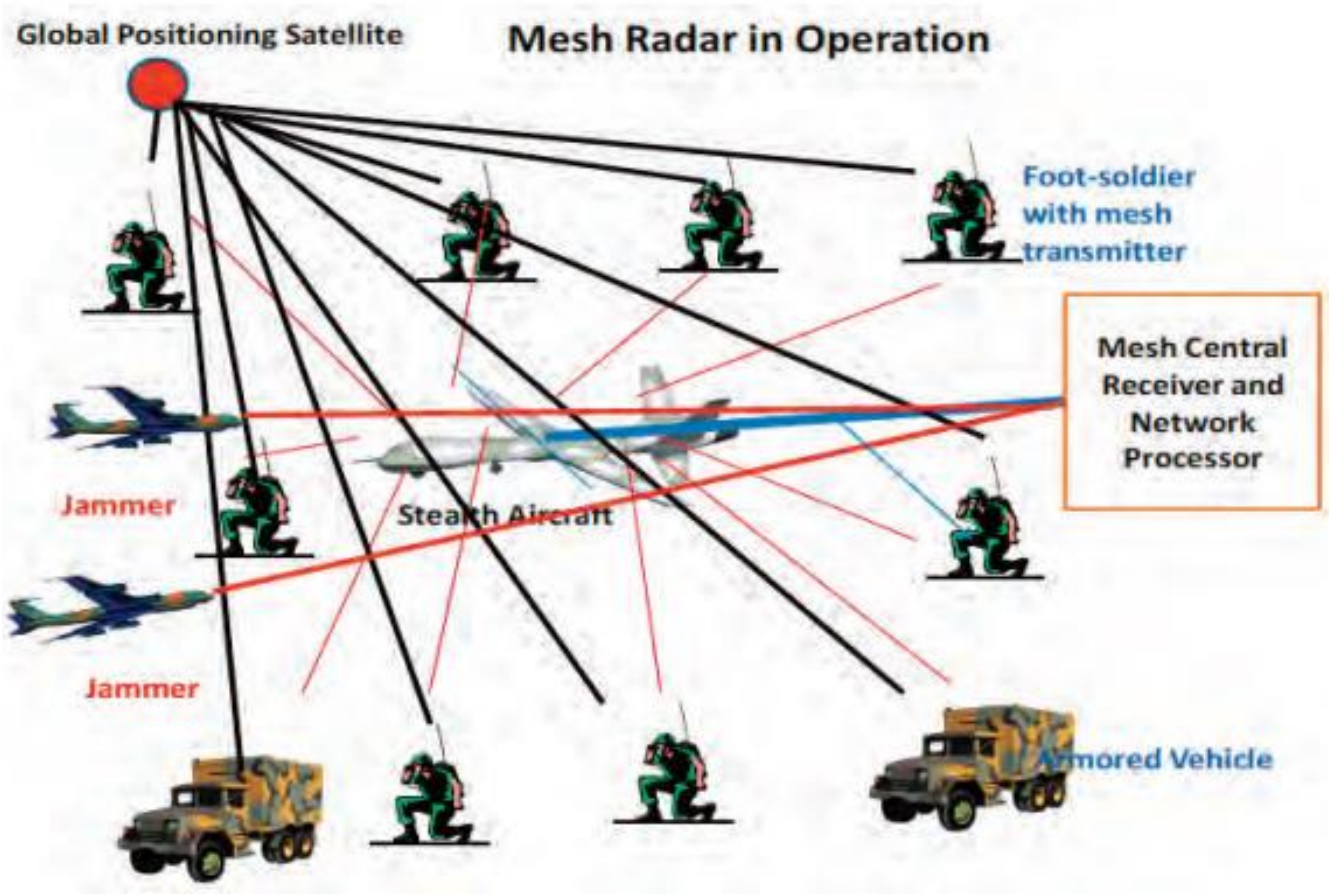
Dream figure from Glaser: FSR for future systems



We need to know if not range but at least angular position of each transmitter (non-cooperative). If spectrum spreading is used ideally the signal shall be decoded

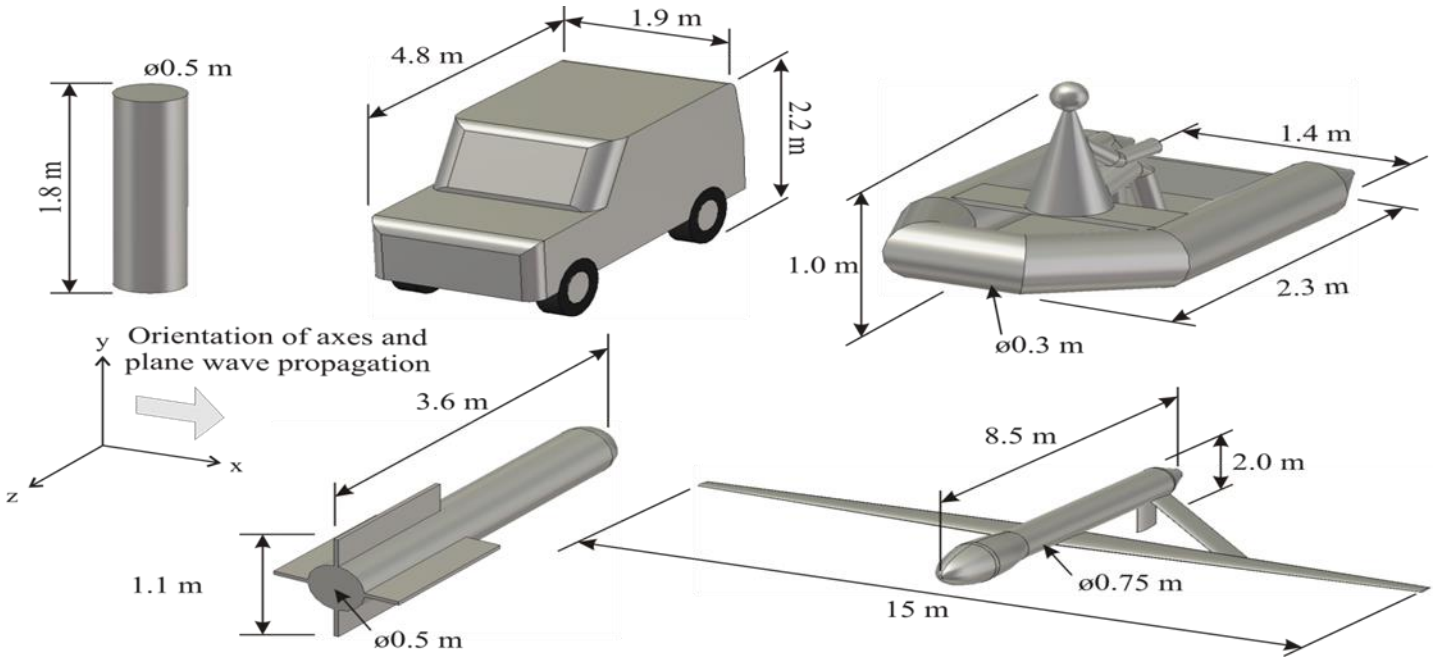
Illuminator of opportunity

Illuminator was Sutton Coldfield transmitting station, UK.

Mast has height of 270.5 m.

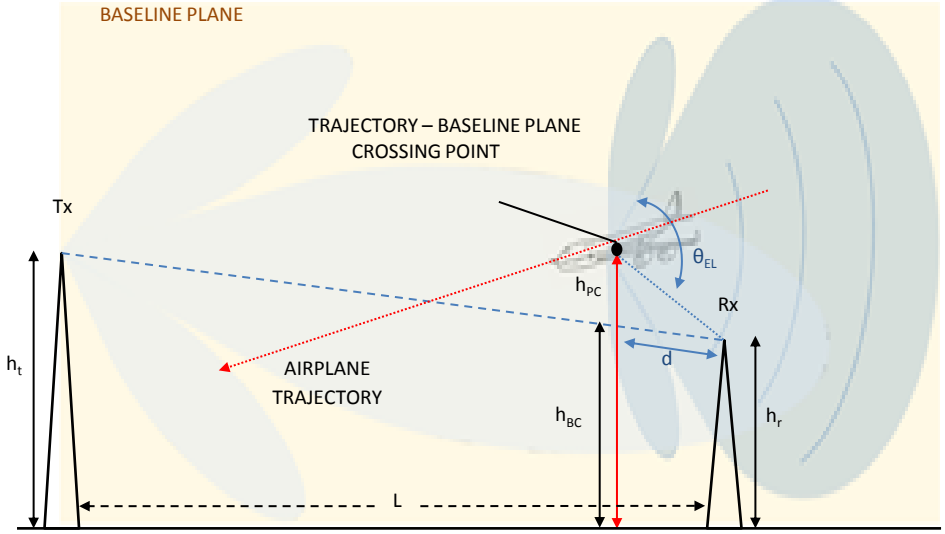
Several of the transmitted broadcasting signals were used for passive FSR application.

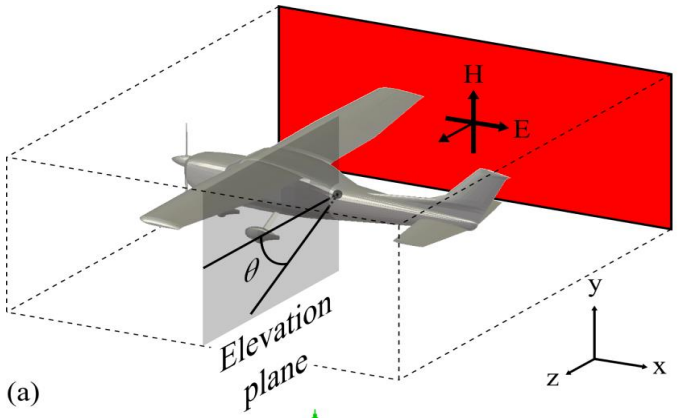
Signal	Frequencies [MHz]	Signal Bandwidth [MHz]	Transmitted Power [kW]
FM	88.3 90.5 92.7 95.6 96.4 97.9	0.150	250 250 250 11 10 250
DAB	222.06 225.65	1.536	8.7 10
DVB-T	650 674	8	200 200

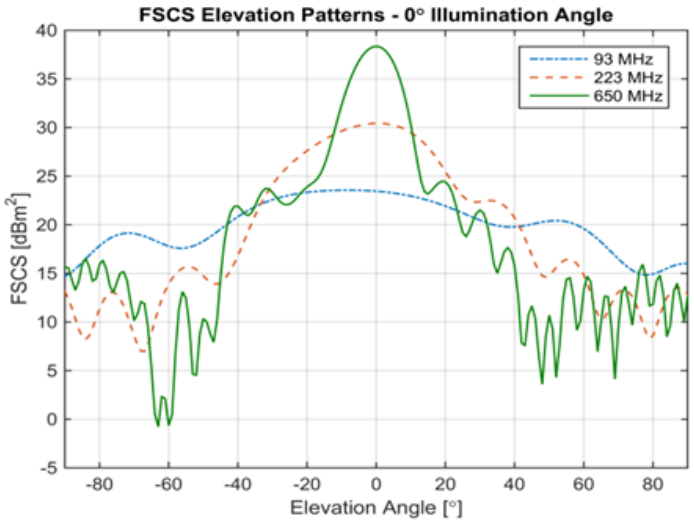


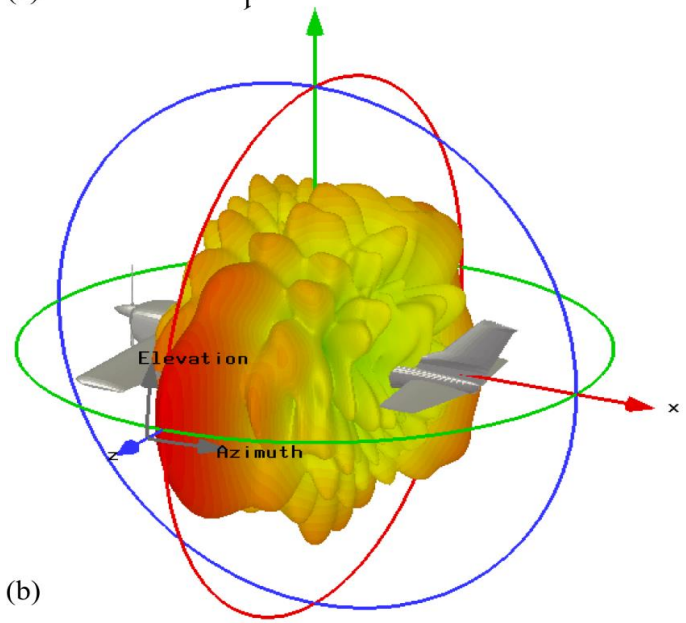
Targets	RCS, dBsm; BR ($\beta = 90^0$)/ FSR ($\beta = 180^0$)			
	100 MHz (FM)	200 MHz (DAB)	400 MHz (DTV)	0.9 GHz (GSM)
Human	6.2/7.6	7.3/11.1	**7.6/15.6**	11.6/22.0
Vehicle	9.7/22.5	7.6/28.2	**-7.4/34.1**	5.4/41.0
Small boat	0.6/2.7	-1.3/6.8	**-9.4/13.0**	-6.6/21.4
Missile	2.9/8.9	1.6/15.3	**-8.0/22.6**	-6.1/29.0
UAV (predator)	4.4/17.6	2.0/23.5	**-1.6/32.9**	-3.0/39.0

Restricted altitude









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Long coherency time = visibility time

	Monostatic						FSR	
$\Delta\varphi$ / Δt (°/s) →	0.2		0.4		0.8		Baseline = 40km v_{Tg} = 50m/s	
λ (m) ↓	Δf_M	$\Delta\tau_M$	Δf_M	$\Delta\tau_M$	Δf_M	$\Delta\tau_M$	Δf_{FS}	$\Delta\tau_{FS}$
3.0	0.8	1.25	1.6	0.63	3.2	0.31	0.013	75
1.5	1.6	0.63	3.2	0.31	6.4	0.16	0.026	37.5
0.75	3.2	0.31	6.4	0.16	12.8	0.09	0.053	18.8
0.3	8.0	0.13	16.0	0.06	32.0	0.03	0.13	7.5
0.1	24.0	0.04	48.0	0.02	96.0	0.01	0.4	2.5
0.03	80.0	0.01	160.0	0.006	320.0	0.003	1.3	0.75

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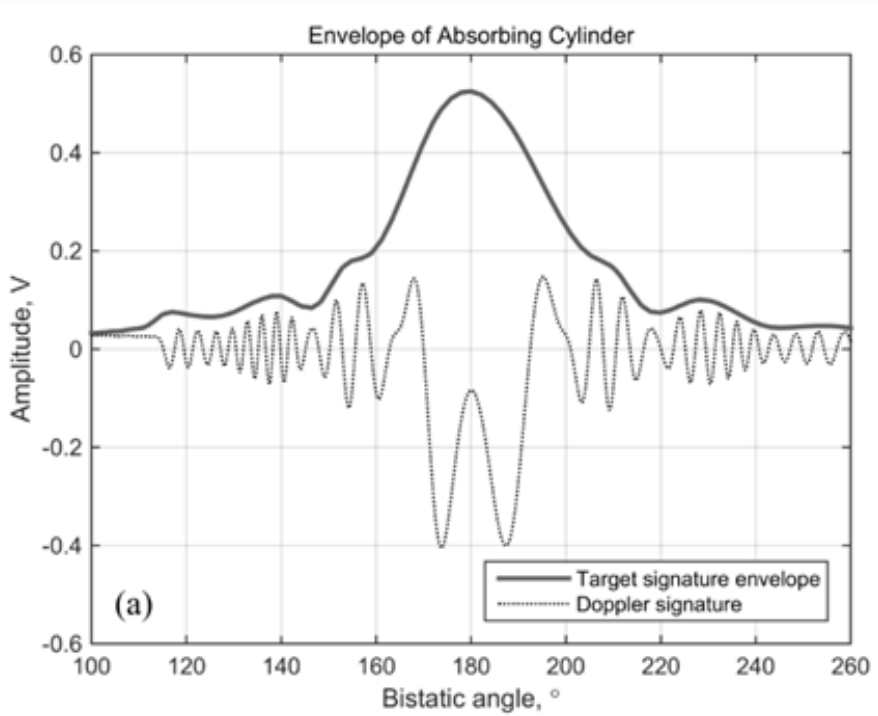
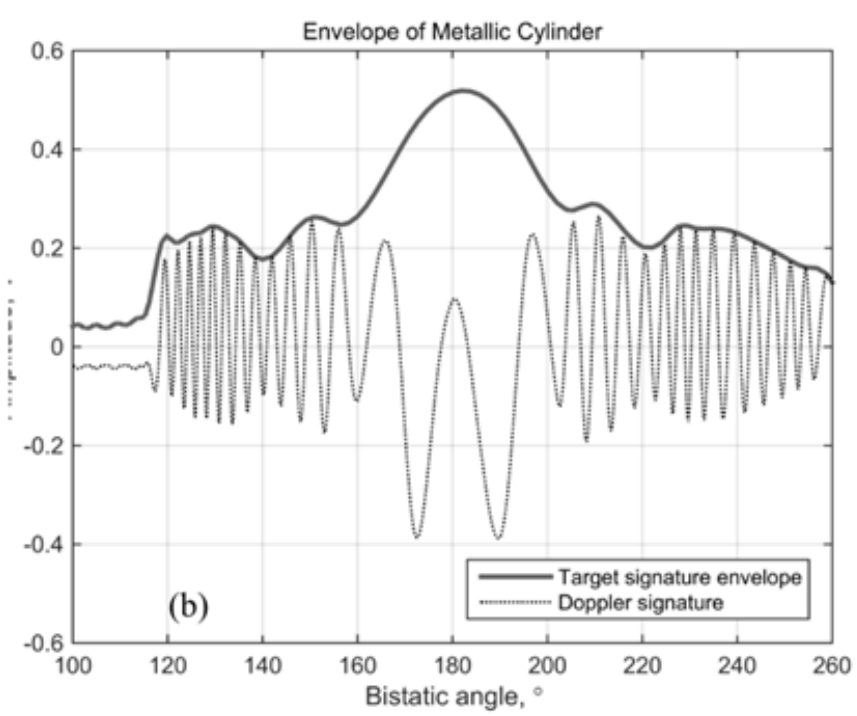
True FS could be seen only for a black body. For any practical target the FS is seen only over a narrow angle



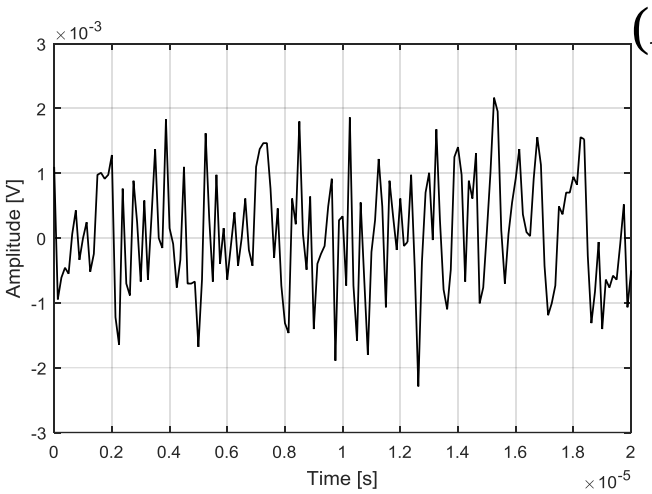


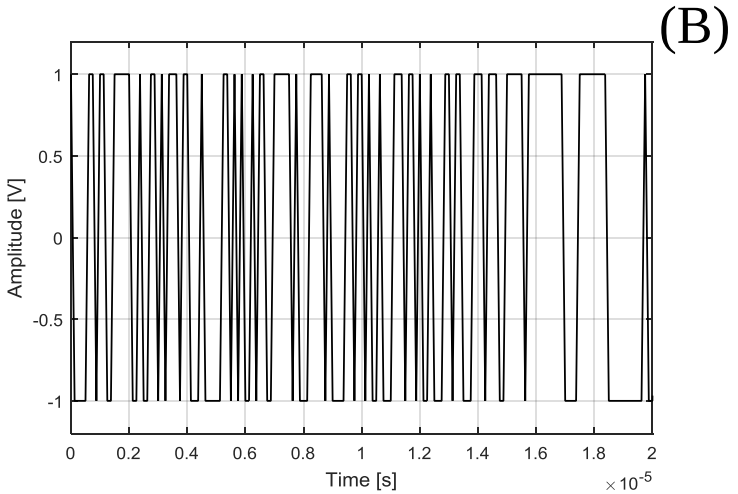
Forward Scatter Target Doppler Signature Extraction

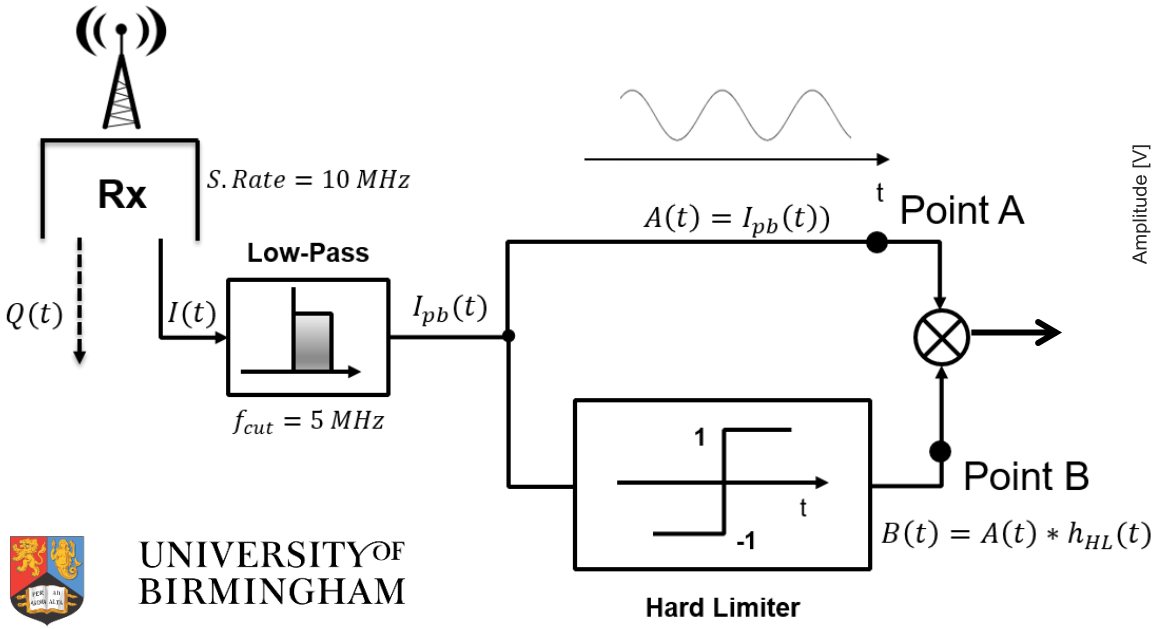
The received baseband signal is split into two copies:

1. In the first the signal stays as it is (A)
2. The second copy is hard-limited, saturating the signal to 1 and -1 for positive and negative amplitude of each sample (B)

These signals are then mixed.







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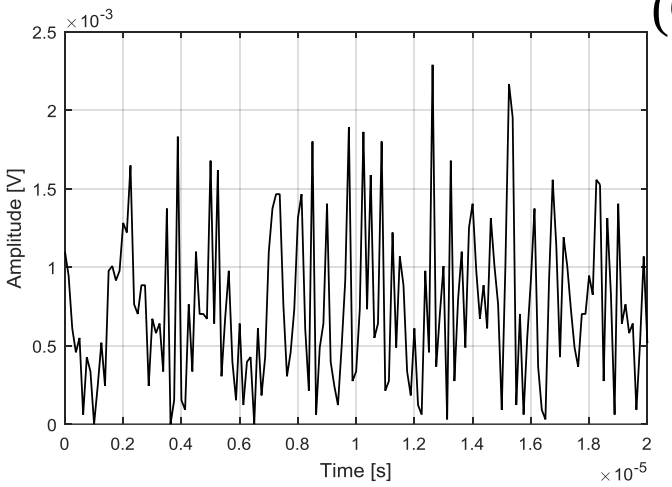
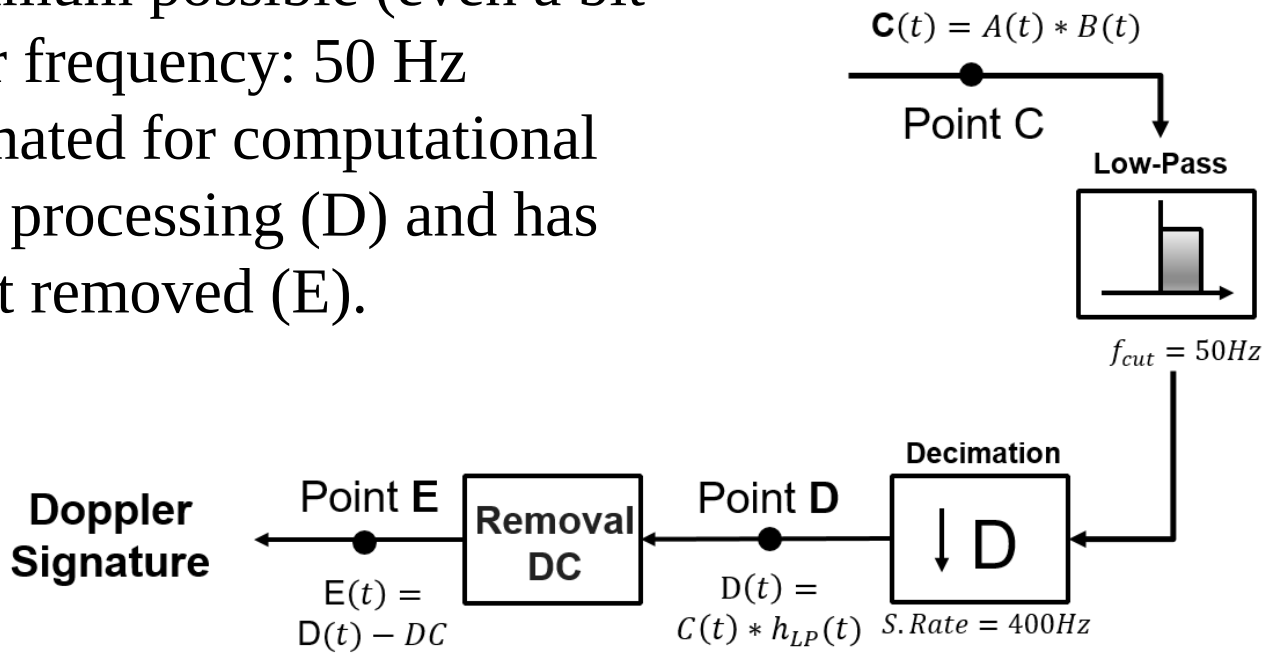
(C)



After mixing (C), signal is passed through an LPF with corresponding cut-off to the maximum possible (even a bit spare) Doppler frequency: 50 Hz
Signal is decimated for computational ease of further processing (D) and has DC component removed (E).



Receiver parameters

A single-node multi-frequency passive FSR system was set-up. It was based on a battery operated NI USRP-2950R which was controlled via LabVIEW 2015.

Parameter	Value
Frequency Range	50 MHz – 2.2 GHz
Programmable LNA	Up to 31.5 dB gain
DVB-T Antenna	Yagi 8dBi, 20˚ azimuth and elevation
DAB Antenna	Yagi 6.2 dBi, 60˚ azimuth and elevation
FM Antenna	Yagi 5 dBi, 110˚ azimuth and 70˚ elevation
Number of channels	2
Receiver Bandwidth	10 MHz

NI USRP-2950R

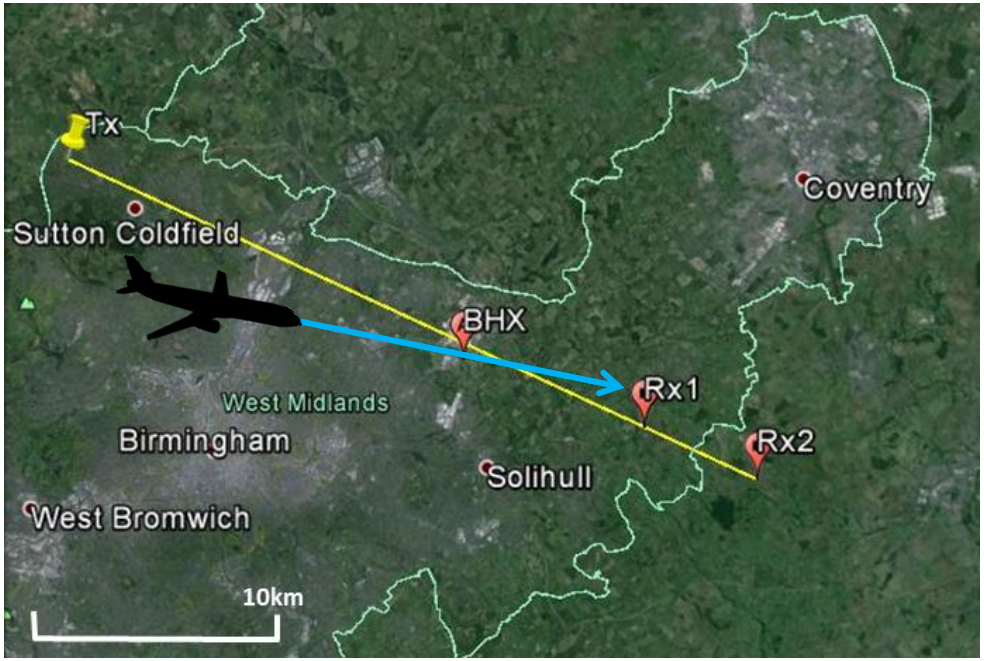
Measurements: Airliners

Experiments were conducted at two points at different distances from the estimated crossing point:

- Rx1 – 6 km, 26 km baseline
- Rx2 – 15 km, 35 km baseline

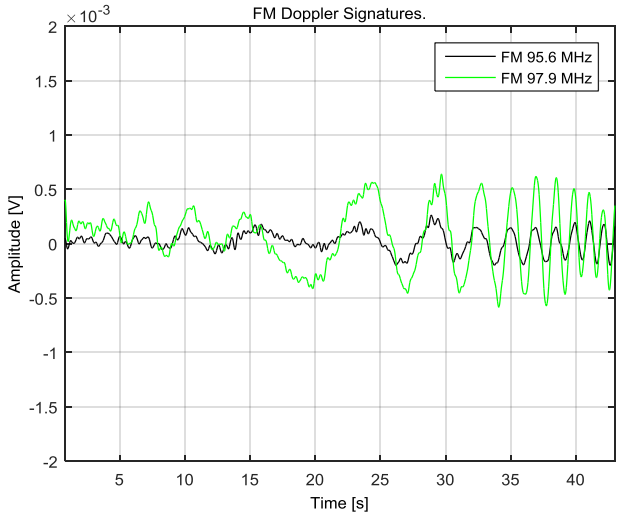
This set-up provided a crossing angle of around 15 degrees. Trajectory is shown in the cyan line.

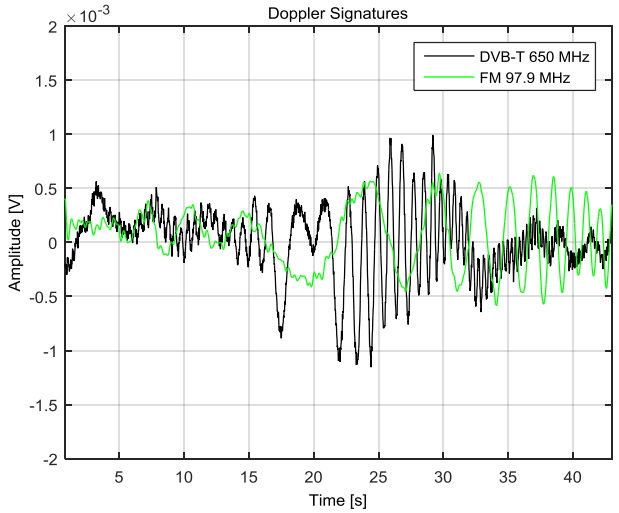
Ground truth was obtained by Flightradar24, providing altitude, location and speed of the targets.

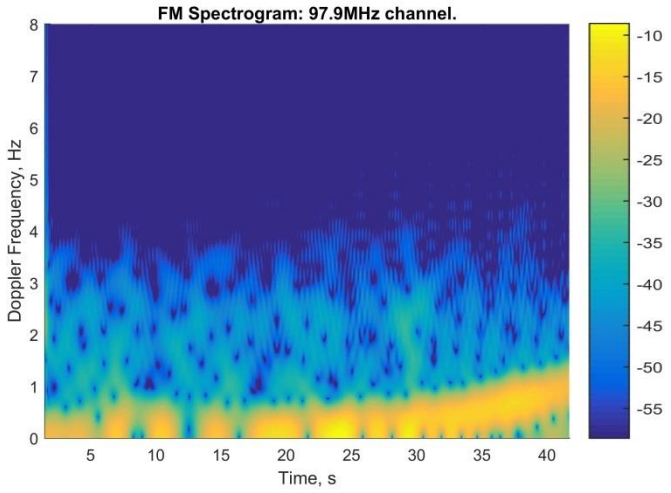


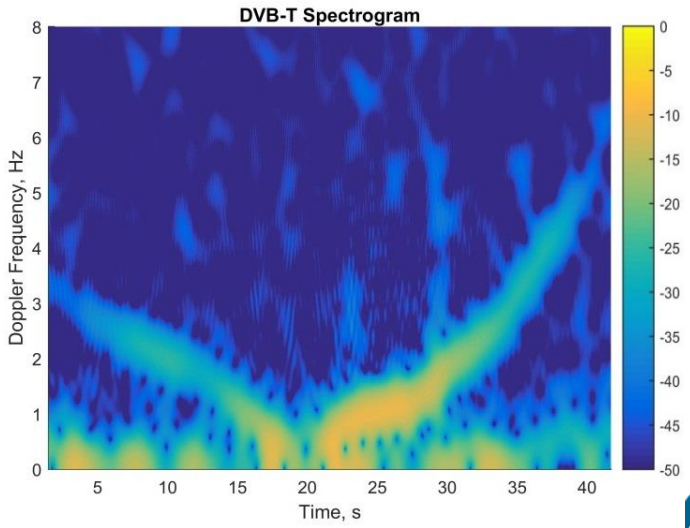
Airplane	Length x Wingspan x Max Height [m]
Airbus A320	37.57 x 35.8 x 11.72
Bombardier Dash8 Q-400	32.84 x 28.42 x 8.34

Airbus A320 Taking off (26 km)









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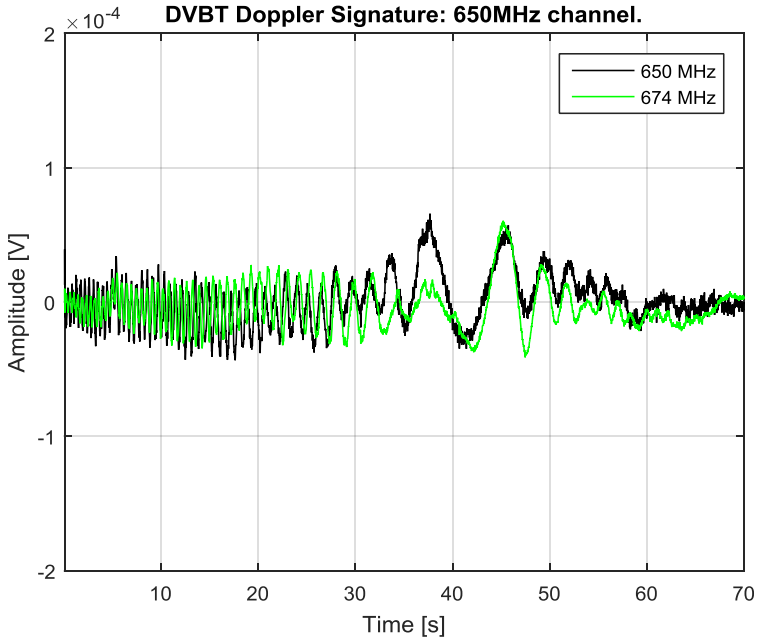
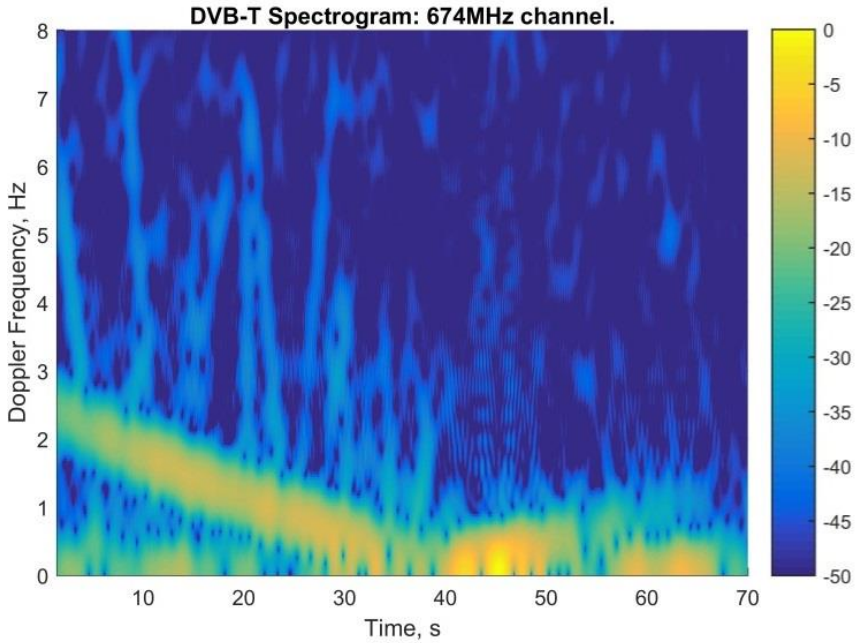
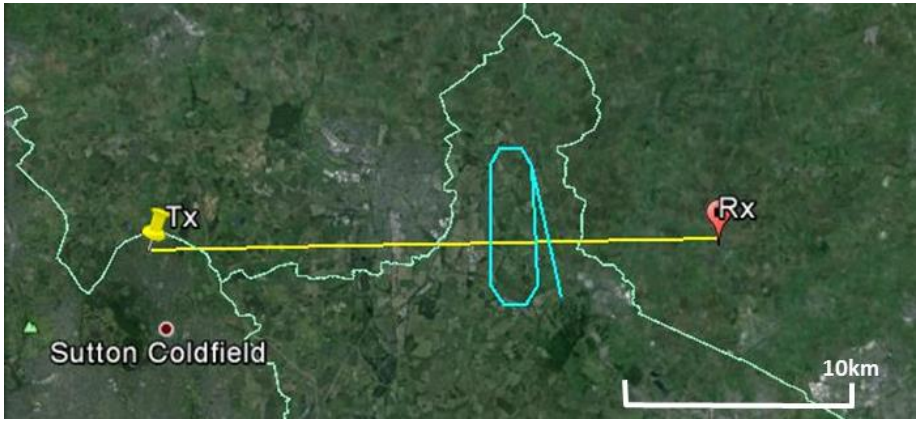
Bombardier Dash8 Q-400 Landing (35 km)





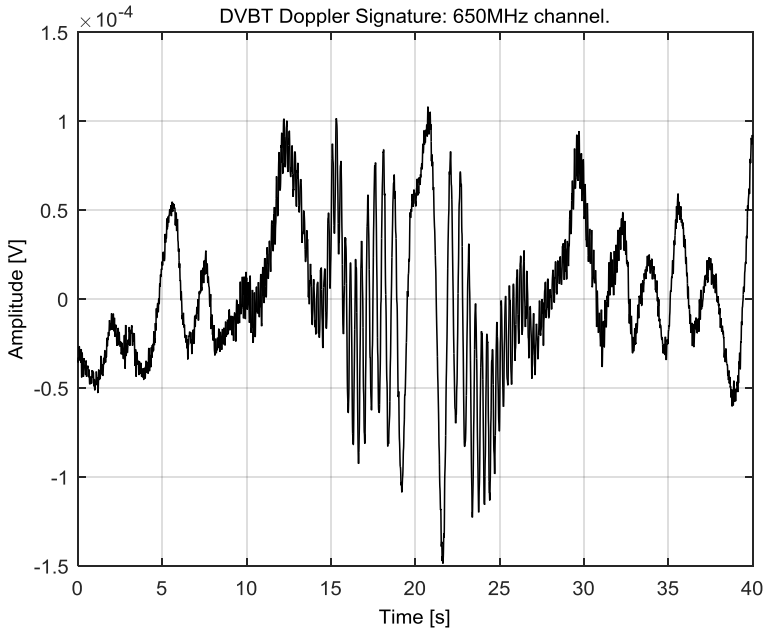
Measurement: Light aircraft

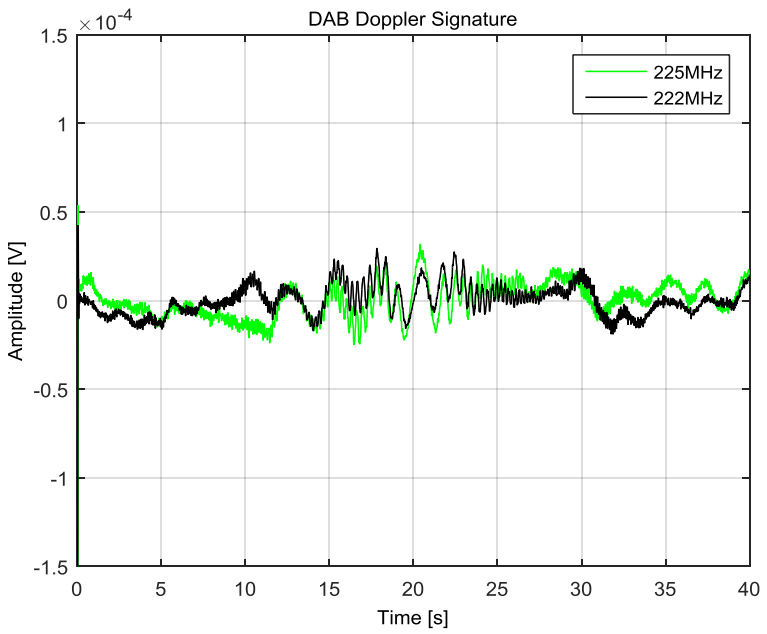
- Rx set-up near Sibson, Leicester, UK, providing baseline of around 25 km.
- Target was Cessna 172: 7.3 m length, 2.3 m height and 11 m wingspan
- Target trajectory (cyan line) was oval-shaped, where the altitude was increased by around 100 m on each pass.
- Three results shown with plane at altitude: 483, 788 and 947 m



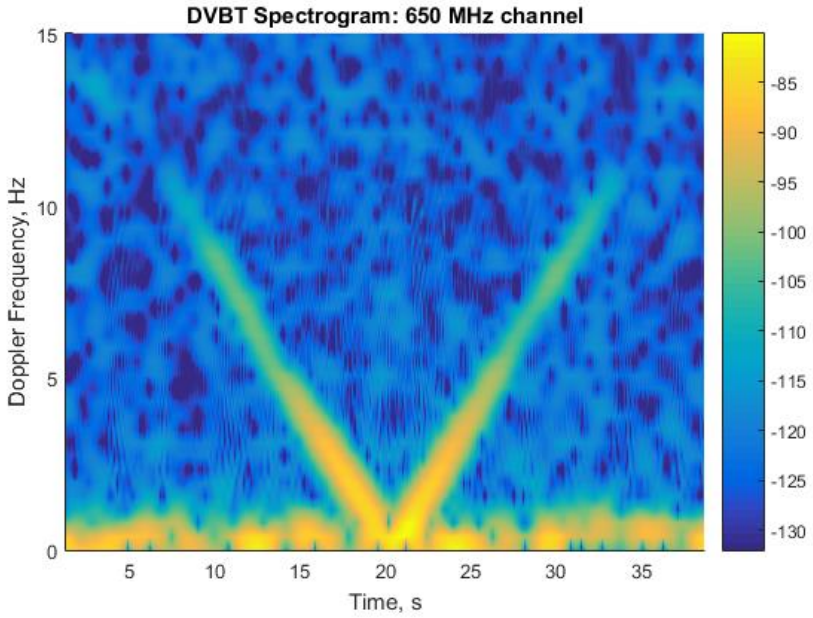
Data	Crossing distance from Rx [km]	Crossing Angle [deg]	Altitude a.s.l. [m]	Recorded Signals
D1	9.1	86	483	DVB-T + DAB
D2	9.0	87	788	DVB-T + FM
D3	7.9	85	947	DVB-T + FM

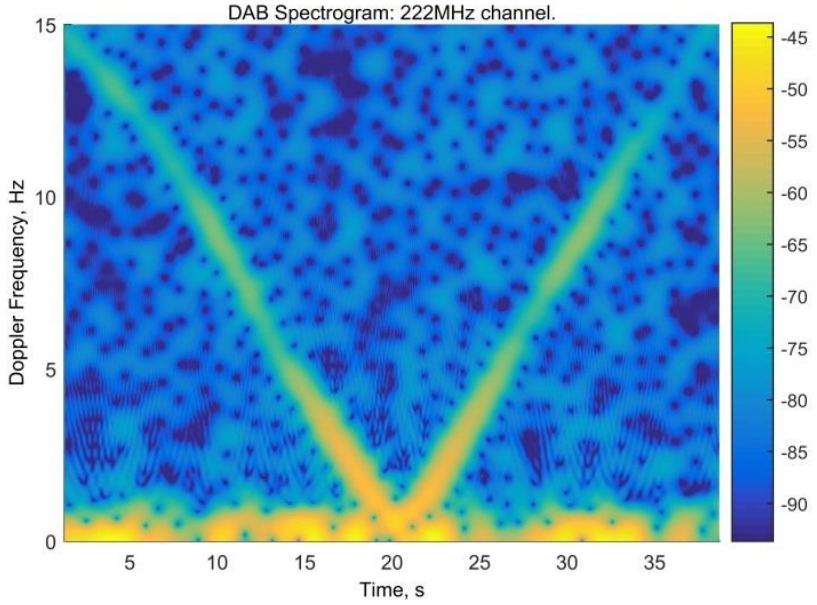
D1 (483 m altitude)



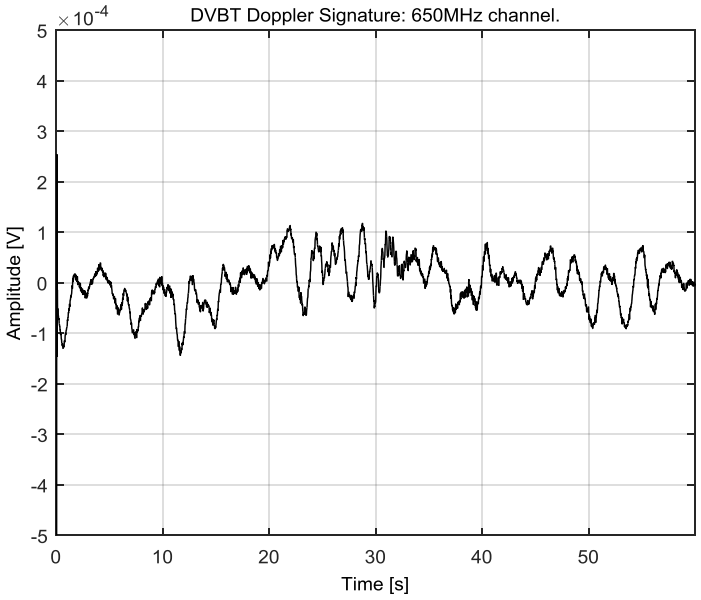


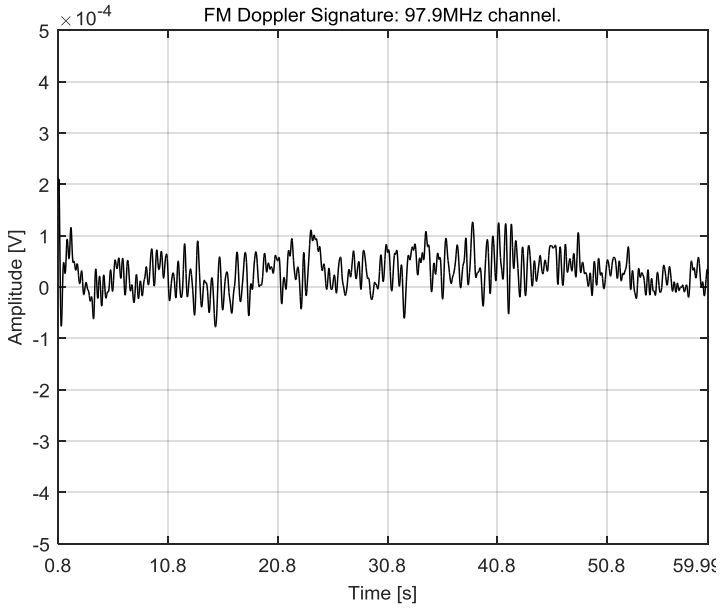
D1 (483 m altitude)



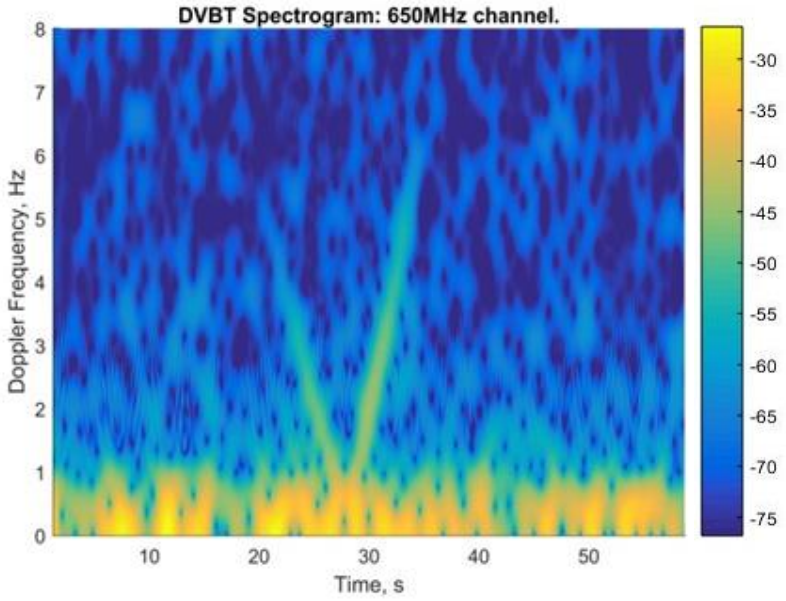


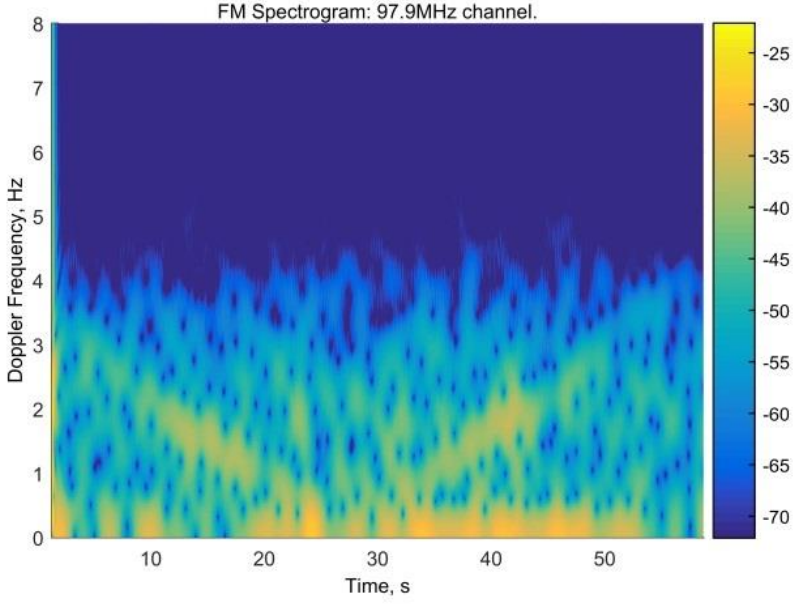
D2 (788 m altitude)



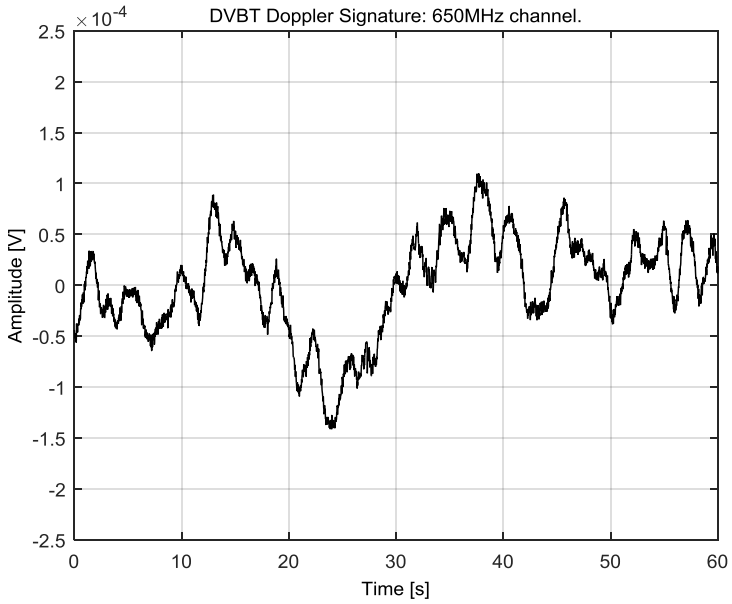


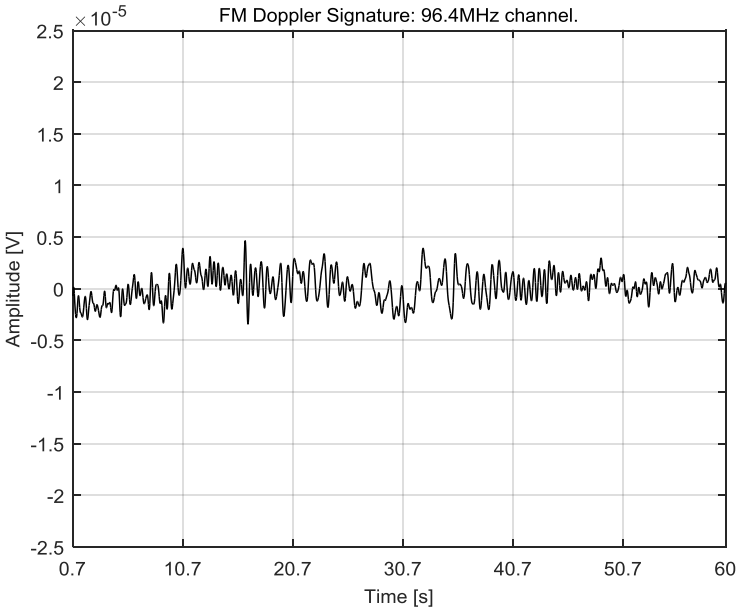
D2 (788 m altitude)



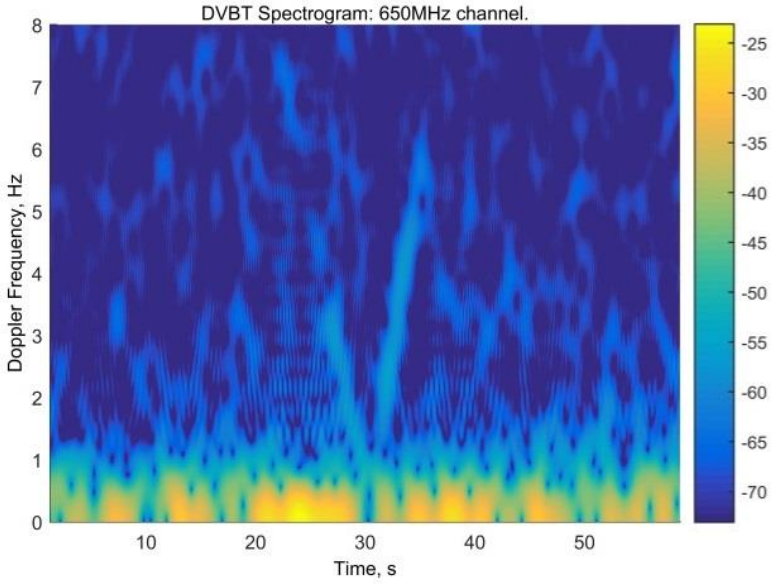


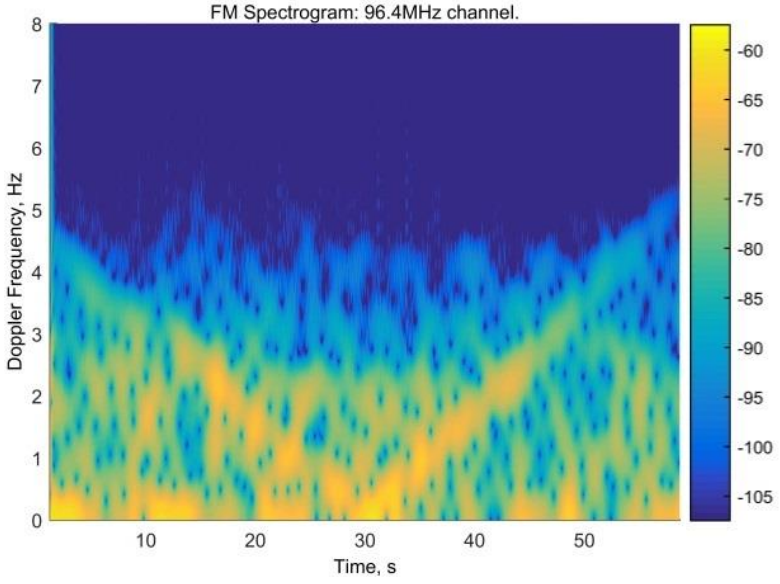
D3 (947 m altitude)





D3 (947 m altitude)





Velocity Estimation

A quasi-optimal approach which is used to extract the motion parameters, where the received target signature was correlated with a bank of waveforms generated for a range of expected values of speed, crossing point and crossing angle.

Estimated and ground truth speeds are shown in the table below for some of the results shown.

Data	Signals	Frequency MHz	Estimated speed km/h	Ground Truth km/h
4	DVB-T	650	248.4	263 by Flightradar24
	DVB-T	674	216.0	
D2	DAB	222	176.4	167 by GPS
		225	176	
	DVB-T	650	188.1	

Very good agreement with ground truth was achieved for both illuminators, for both target types and for both types of ground truth.

Conclusion (provisional)

- FSR is not sensitive to the type of transmit signal modulation if proper signal processing algorithms are used
- Passive FSR could be considered as a subclass of Passive BR presumably for perimeters protection
- Multi band multi frequency FSR is the subject of study and have (?!☺) a lot of potential for stealth targets detection and wider for air targets detection, tracking and automatic classification.

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Thank you!

Any questions?