EUROPE'S PREMIER MICROWAVE, RF, WIRELESS AND RADAR EVENT
EUROPEAN MICROWAVE WEEK
IFEMA FERIA DE MADRID, SPAIN
23-28 SEPTEMBER 2018
www.eumweek.com
EuMW2018 PASSION FOR MICROWAVES

WS 05

mmWave Train-to-Train Communications for Next Generation Railways

Stephan Sand, Mohammad Soliman, Paul Unterhuber
German Aerospace Center (DLR)
stephan.sand@dlr.de

48TH EUROPEAN MICROWAVE CONFERENCE 2018
The 48th European Microwave Conference

EuMIC 2018
The 13th European Microwave Integrated Circuits Conference

EURAD 2018
The 15th European Radar Conference

New Railway Applications

Current situation in road traffic:

- Very efficient use of roads
- 75% of freight, 82% of passengers
- Many accidents, traffic jams, less energy efficient

Current situation in railways:

- Very safe and energy efficient
- 18% of freight, 8% of passengers
- Inefficient use of railways due to old safety system

New Railway Applications

Evolution in road traffic:

- Electric vehicles
- Connected and autonomous driving

- Platooning

Evolution in railways:

European Rail Traffic Management System (ERTMS)

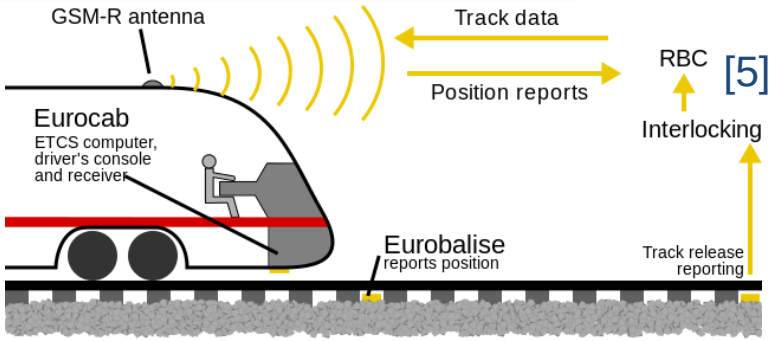
- GSM-R
- European Train Control System (ETCS)
  - Level 2:
    fixed block, no lineside signals, speed and track information continuously communicated with GSM-R into cockpit
  - Status:
    Swiss Railways for all train lines above 160 km/h, DB only Erfurt-Leipzig, Spain Madrid-Barcelona

New Railway Applications

Evolution in railways:
European Train Control System (ETCS)

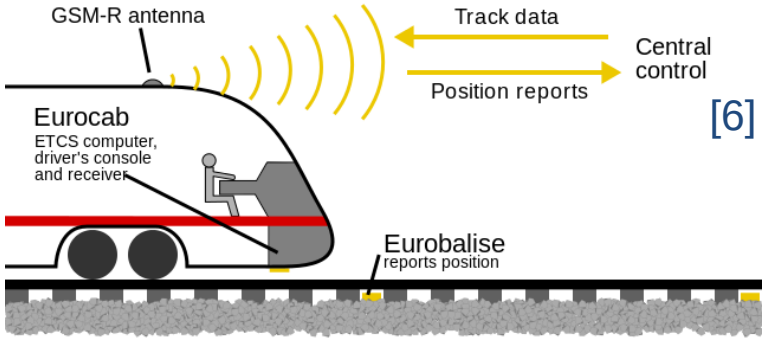
~2 min separation, 10 km for high speed train

- Level 2 fixed block
  - One train in a block
  - Distance to next train ≥ absolute braking distance, i.e. train can break at full speed and stop before entering next block



~0.5 min separation, 3 km for high speed train

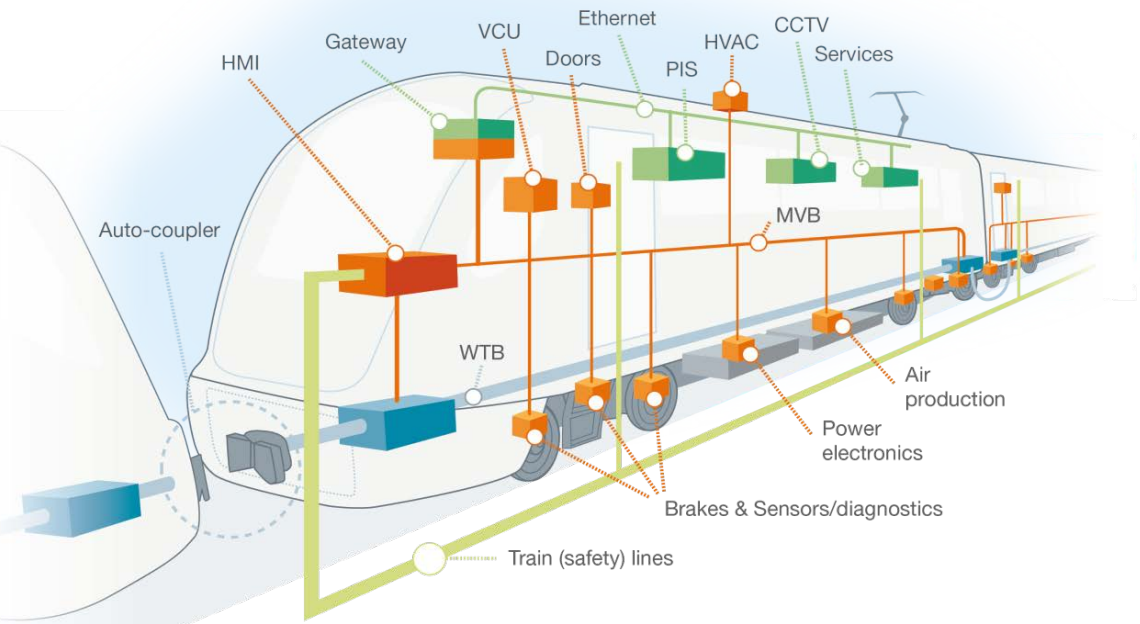
- Level 3 moving block
  - One train in a block
  - Block moves with train
  - Distance to next train = absolute braking distance



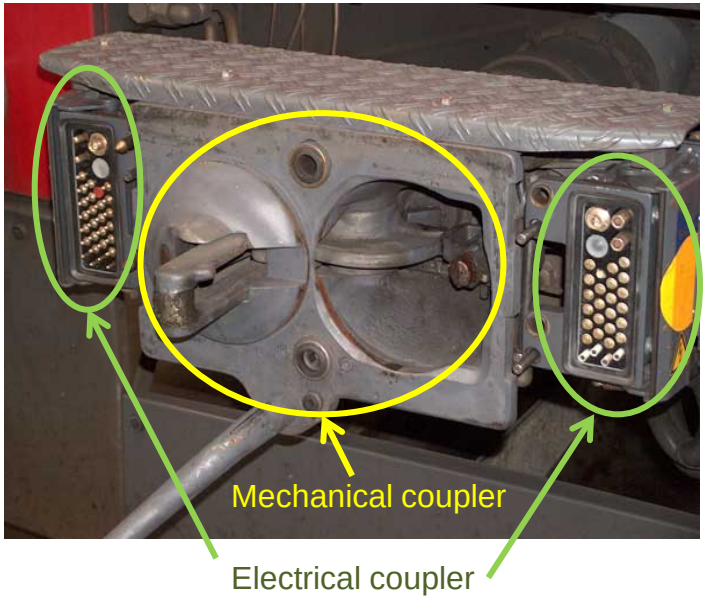
➔ New railway applications to further increase efficiency and flexibility

New Railway Applications

Wireless Train Control and Monitoring System (TCMS)

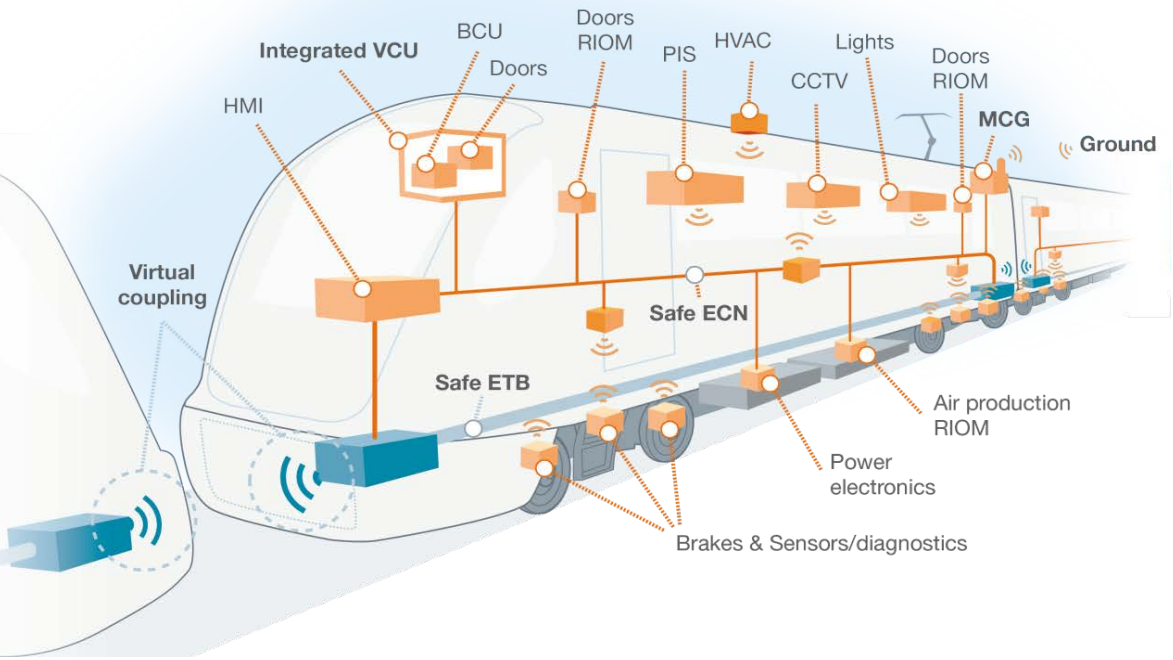


[7]



New Railway Applications

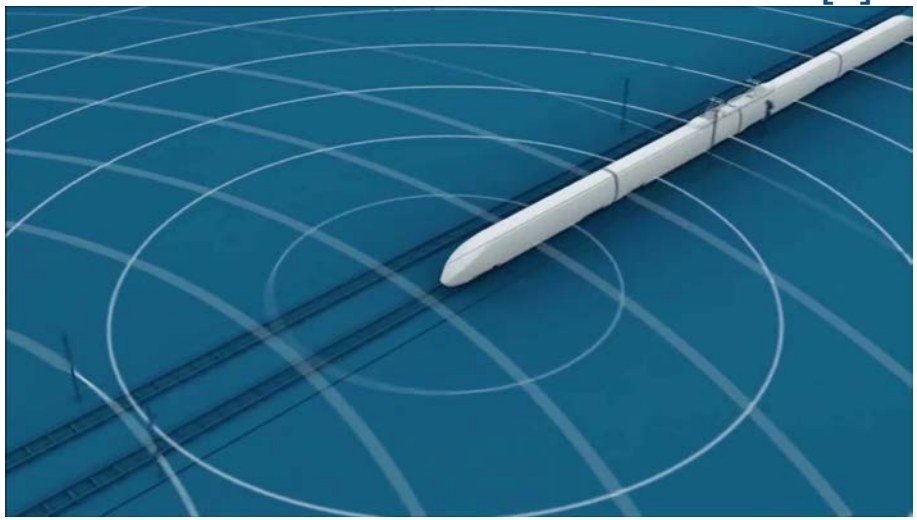
Wireless Train Control and Monitoring System (TCMS)



[7]

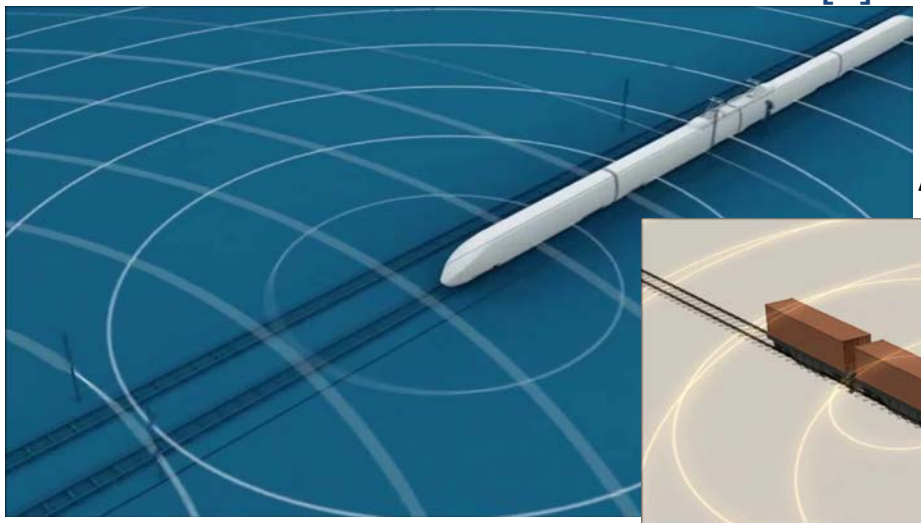
New Railway Applications

Autonomous trains: Collision avoidance [8]



New Railway Applications

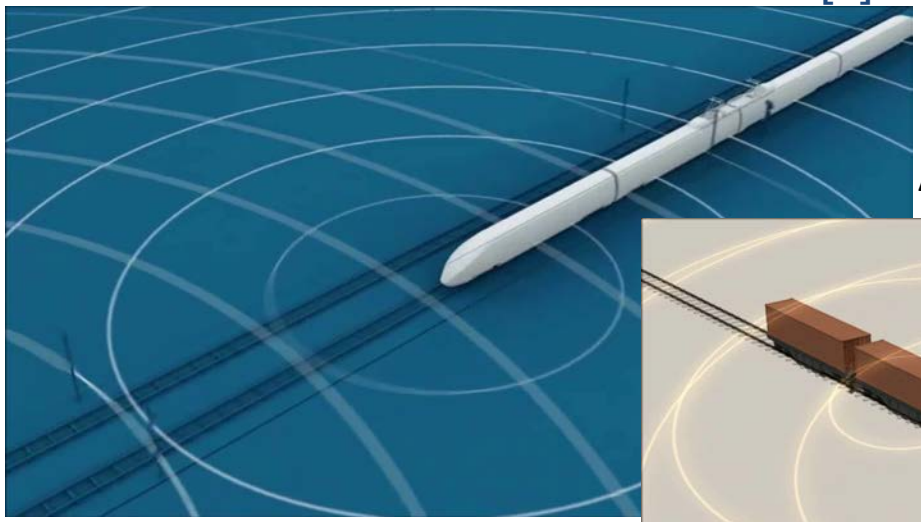
Autonomous trains: Collision avoidance [8]



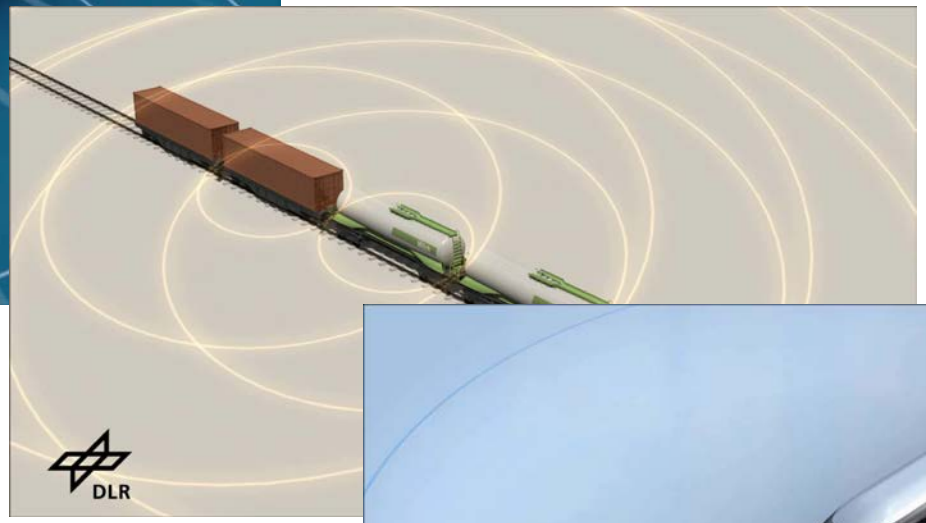
Remote control:
Automatic coupling [9]

New Railway Applications

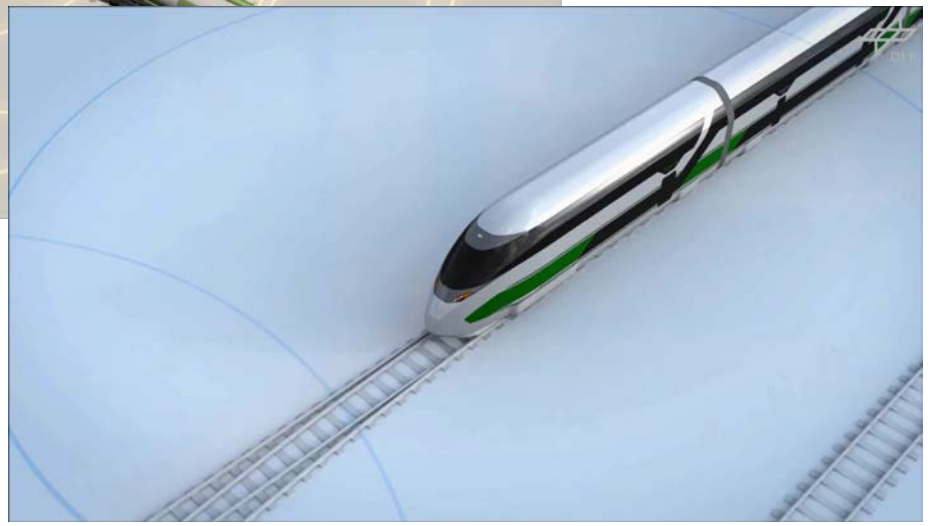
Autonomous trains: Collision avoidance [8]



Remote control:
Automatic coupling [9]



Virtual coupling:
Platooning [10]



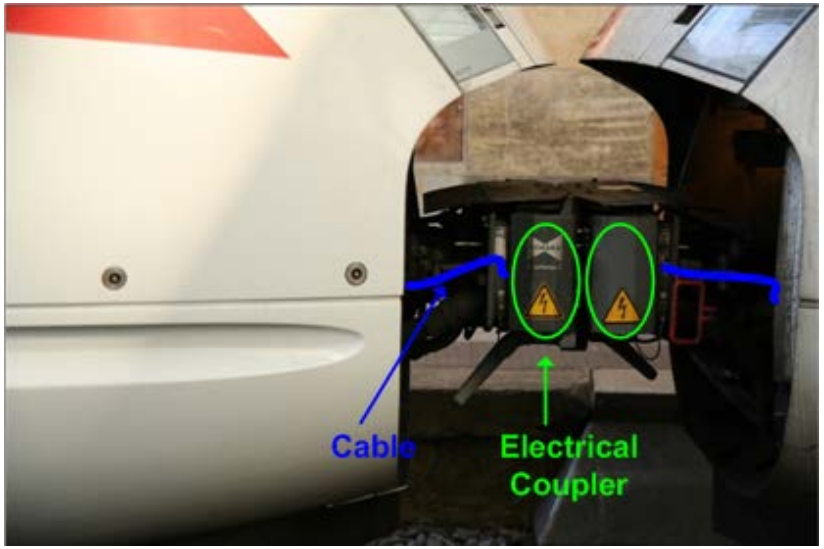
Ultra-reliable low-latency communications and ranging essential for enabling new safety relevant railway applications

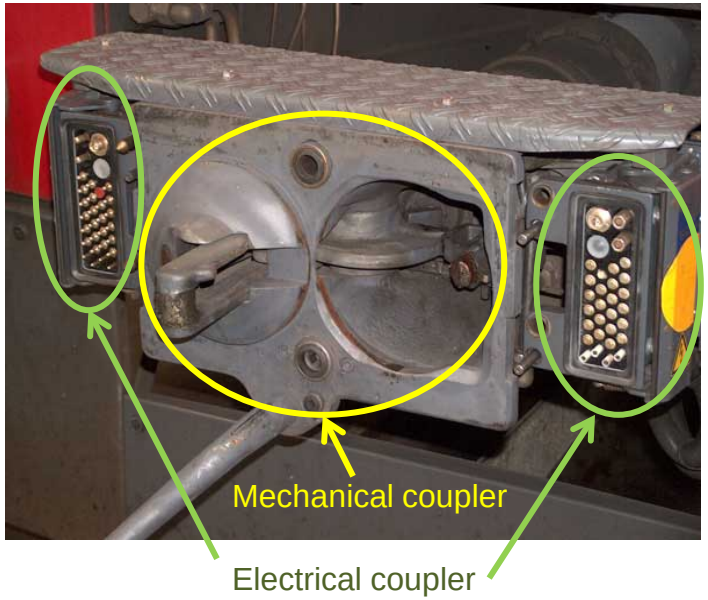
Automatic Coupling [9]

- Reliable wireless communication in industry
- Provide URLL communications and ranging (URLLC&R) over short distances
- Monitor train integrity, i.e. distance between coupled train sets and wagons

SBDist [10]

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung



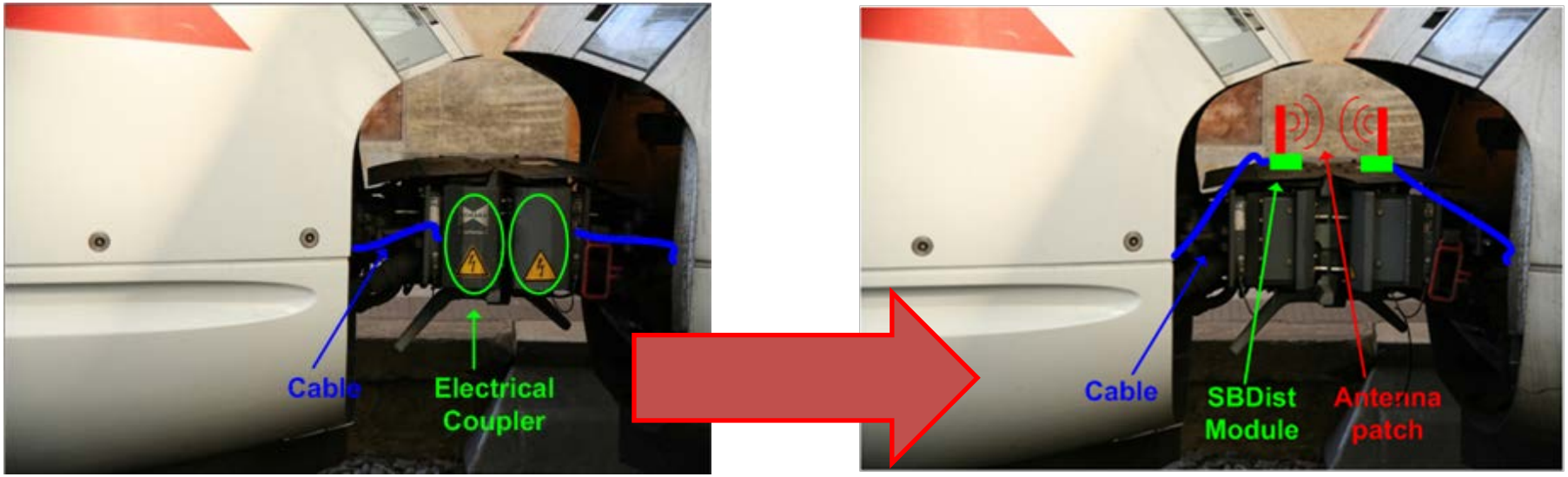


Automatic Coupling [9]

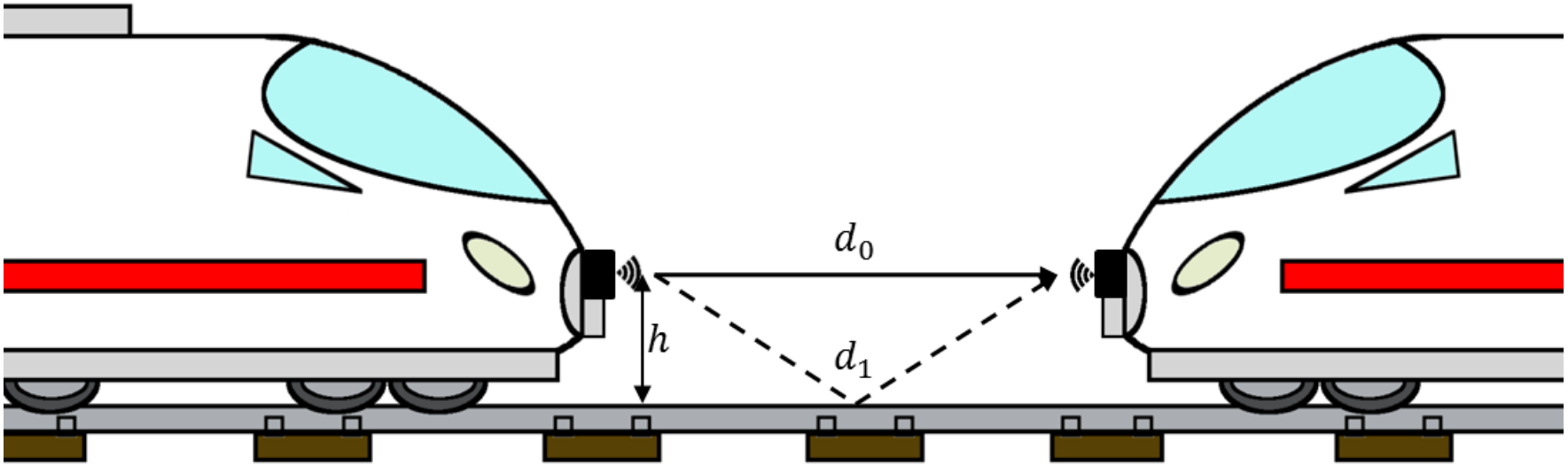
- Reliable wireless communication in industry
- Provide URLL communications and ranging (URLLC&R) over short distances
- Monitor train integrity, i.e. distance between coupled train sets and wagons

SBDist [10]

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung



Automatic Coupling: Channel & System Model



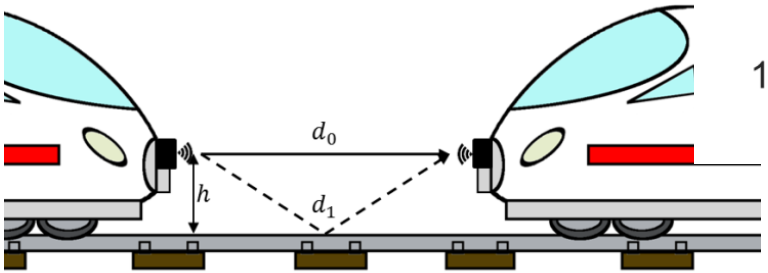
Two-path channel model: $h_c(t) = a_0\delta(t-\tau_0)e^{-\varphi(\tau_0)} + a_1\delta(t-\tau_1)e^{-\varphi(\tau_1)}$

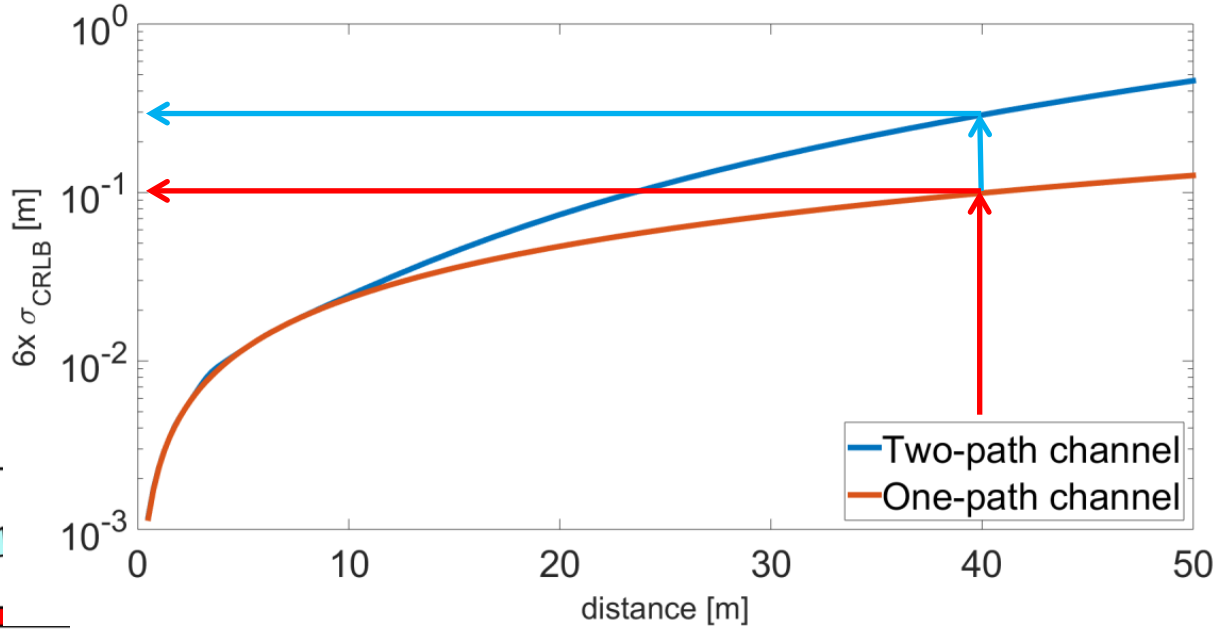
System model: $y[n] = a_0 s\left[n - \frac{\tau_0}{T_s}\right]e^{-\varphi(\tau_0)} + a_1 s\left[n - \frac{\tau_1}{T_s}\right]e^{-\varphi(\tau_1)}$

Automatic Coupling: Cramér Rao Lower Bounds

Cramér Rao Lower Bound (CRLB) versus distance between two transmitters

6σ [m] ➔ reliability of 99.9997% for ranging (beyond 5G URLLC&R)



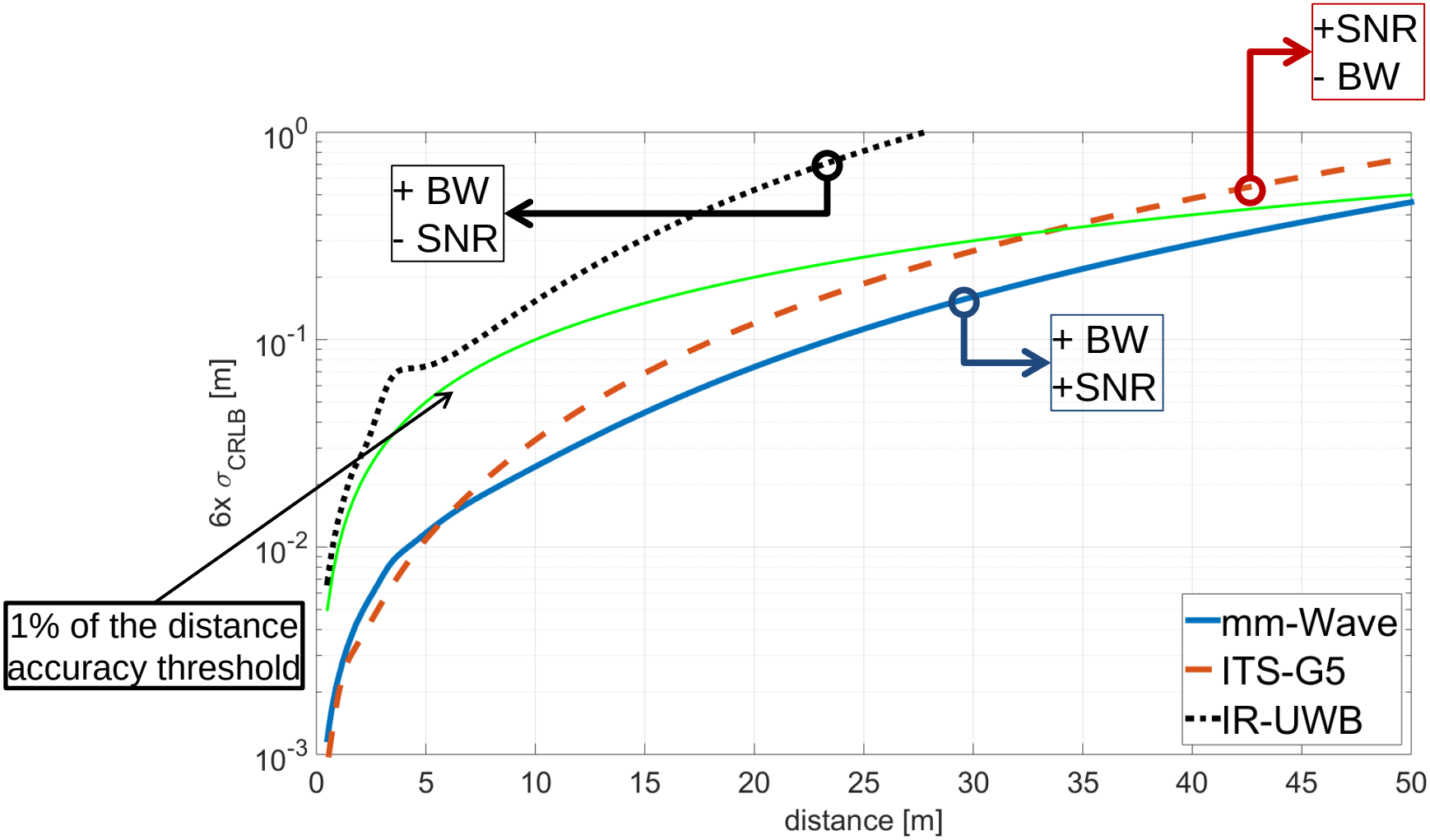


Automatic Coupling: CRLB Results

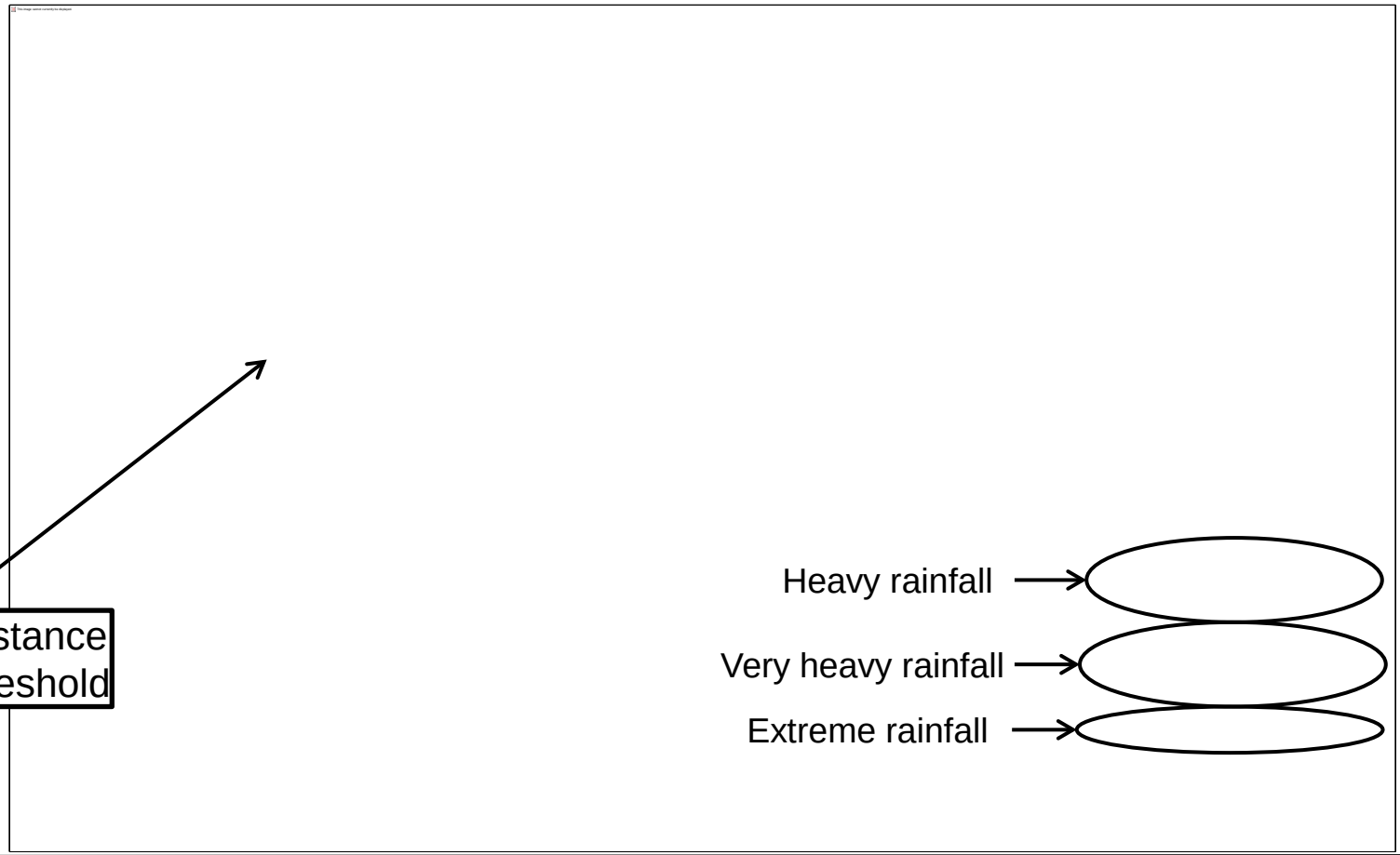
Comparison of three wireless systems:

	mmWave	ITS-G5	IR-UWB
Center Frequency	60 GHz	5.9 GHz	6 GHz
EIRP	31 dBm	31 dBm	-14.5 dBm
Pulse shape	Raised Cosine	OFDM	Second-order Gaussian monocycle
BW	500 MHz	10 MHz	500 MHz
Sampling period	0.2 nsec	10 nsec	0.2 nsec
Number of Observed samples	500 k	10 k	500 k
Height from ground	0.5 m		
Distance between nodes	From 0.5 to 50 m		

Automatic Coupling: CRLB Results



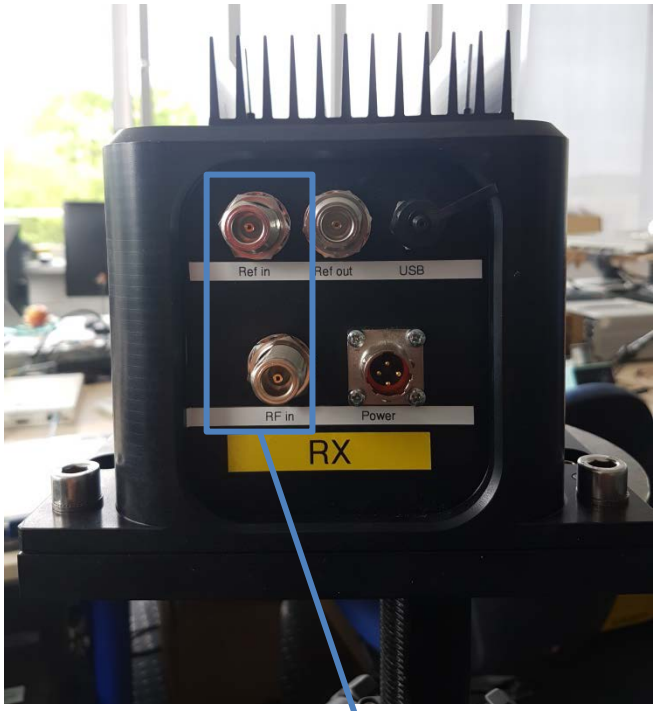
Automatic Coupling: CRLB Results
Rain Effect



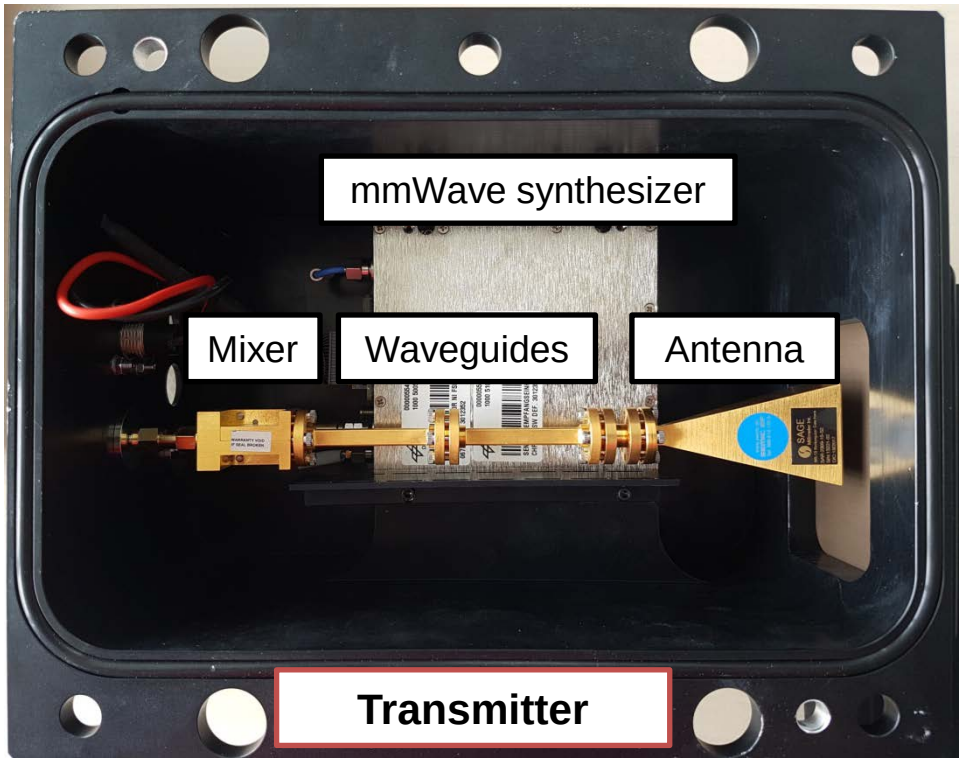
Automatic Coupling: Hardware Description – RUSK-DLR Channel Sounder

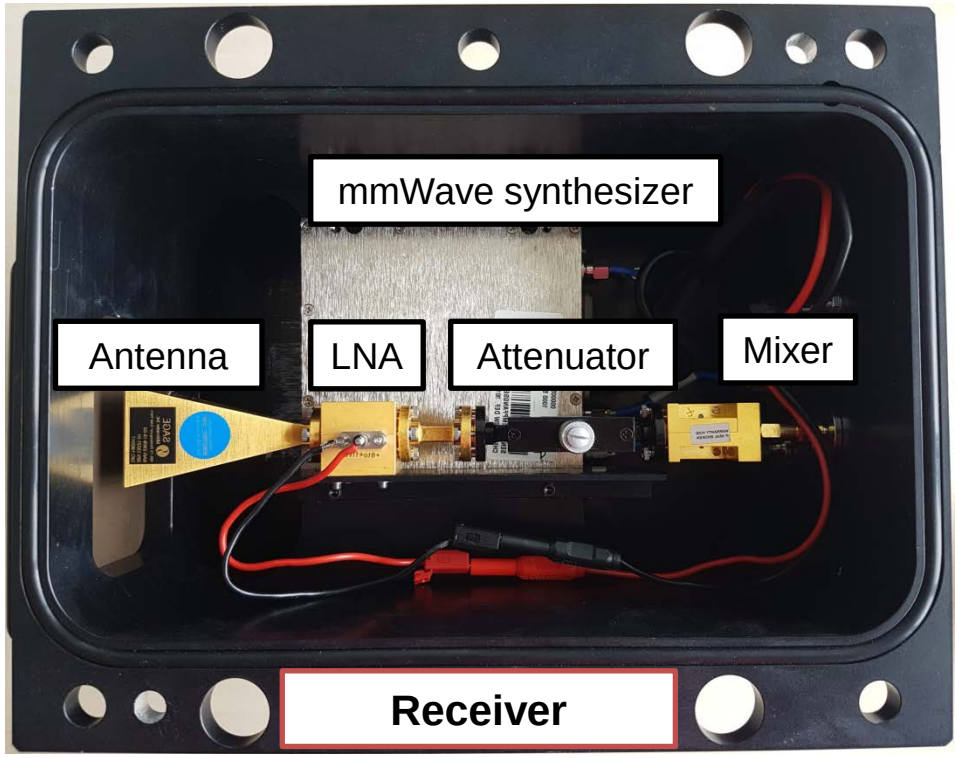
- Center frequency: up to 5.2 GHz
- Bandwidth: 120 MHz
- Signal period: 12.8 µs
- Measurement time grid: 1.024 ms
- Max. Doppler frequency: ±488 Hz
- Rubidium clocks: 10 MHz

Automatic Coupling: Hardware Description – mmWave Frontend



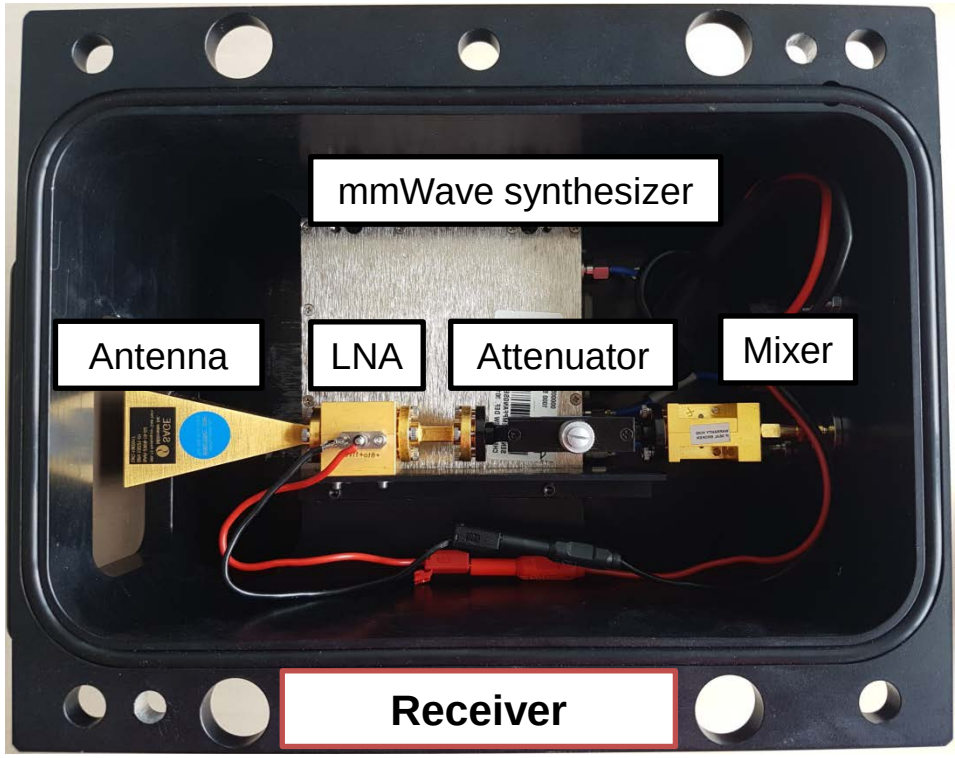
Automatic Coupling: Hardware Description – mmWave Frontend



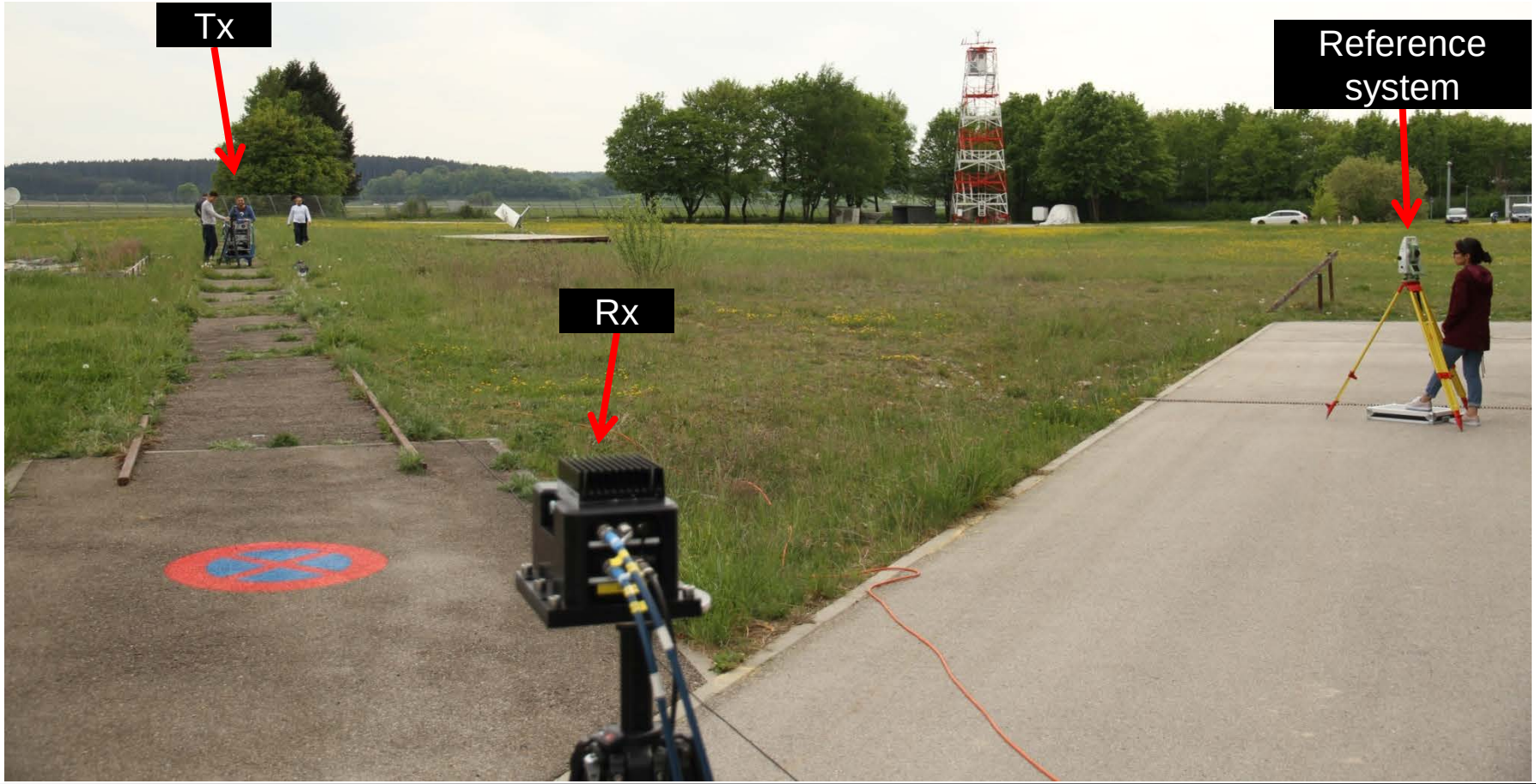


Automatic Coupling: Hardware Description – mmWave Frontend

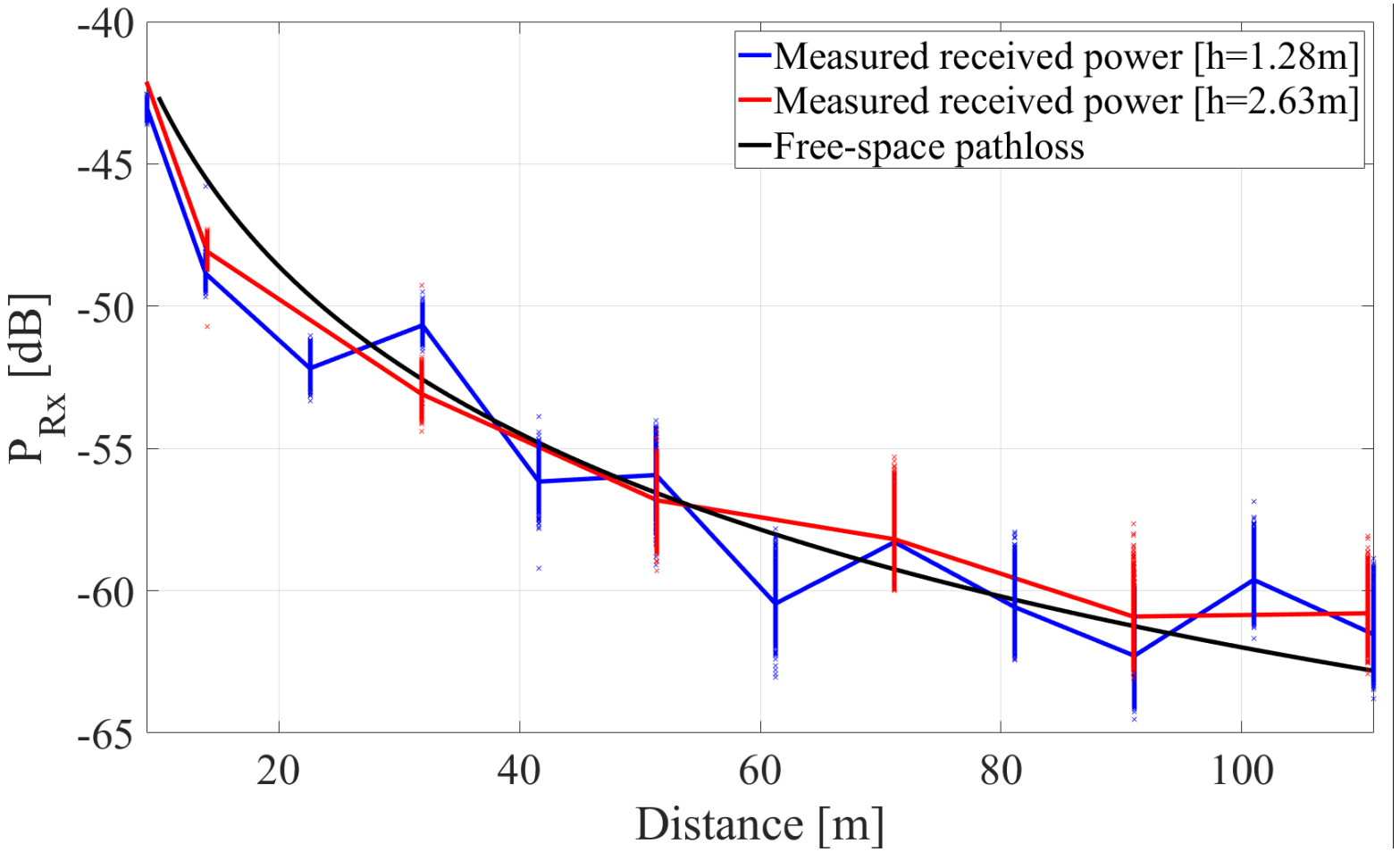
- mmWave synthesizer: Output frequency range 50 to 67 GHz
- Mixer: Waveguide up- and down-converters
- Attenuator: 0-30 dB waveguide variable attenuator
- LNA: 20 dB low noise amplifier with 3.5 dB noise figure
- Antenna: Directive rectangular horn antenna with 12° 3 dB beam width and 23 dB gain



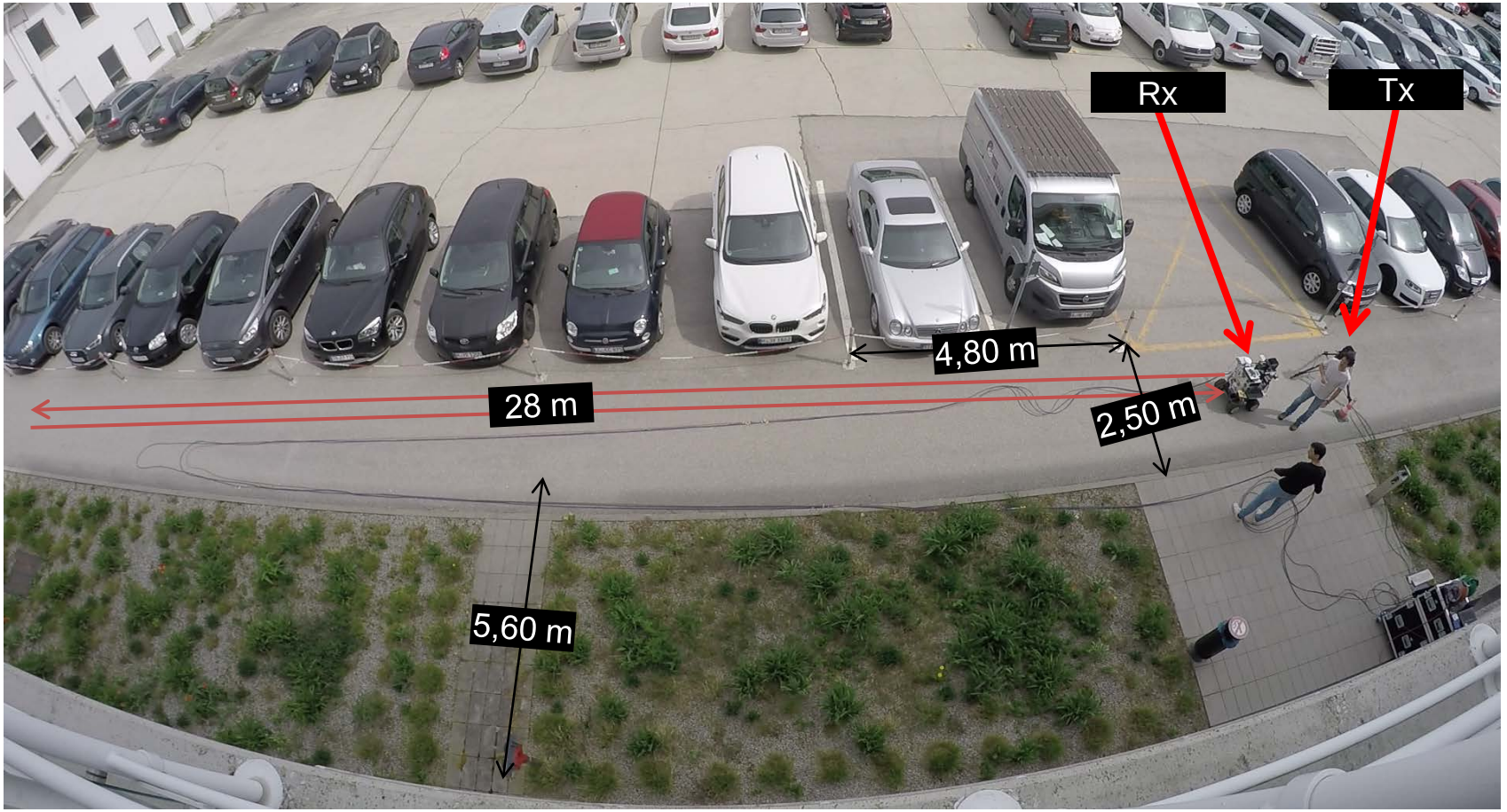
Automatic Coupling: Open field Measurements



Automatic Coupling: Open field Measurements, First Results

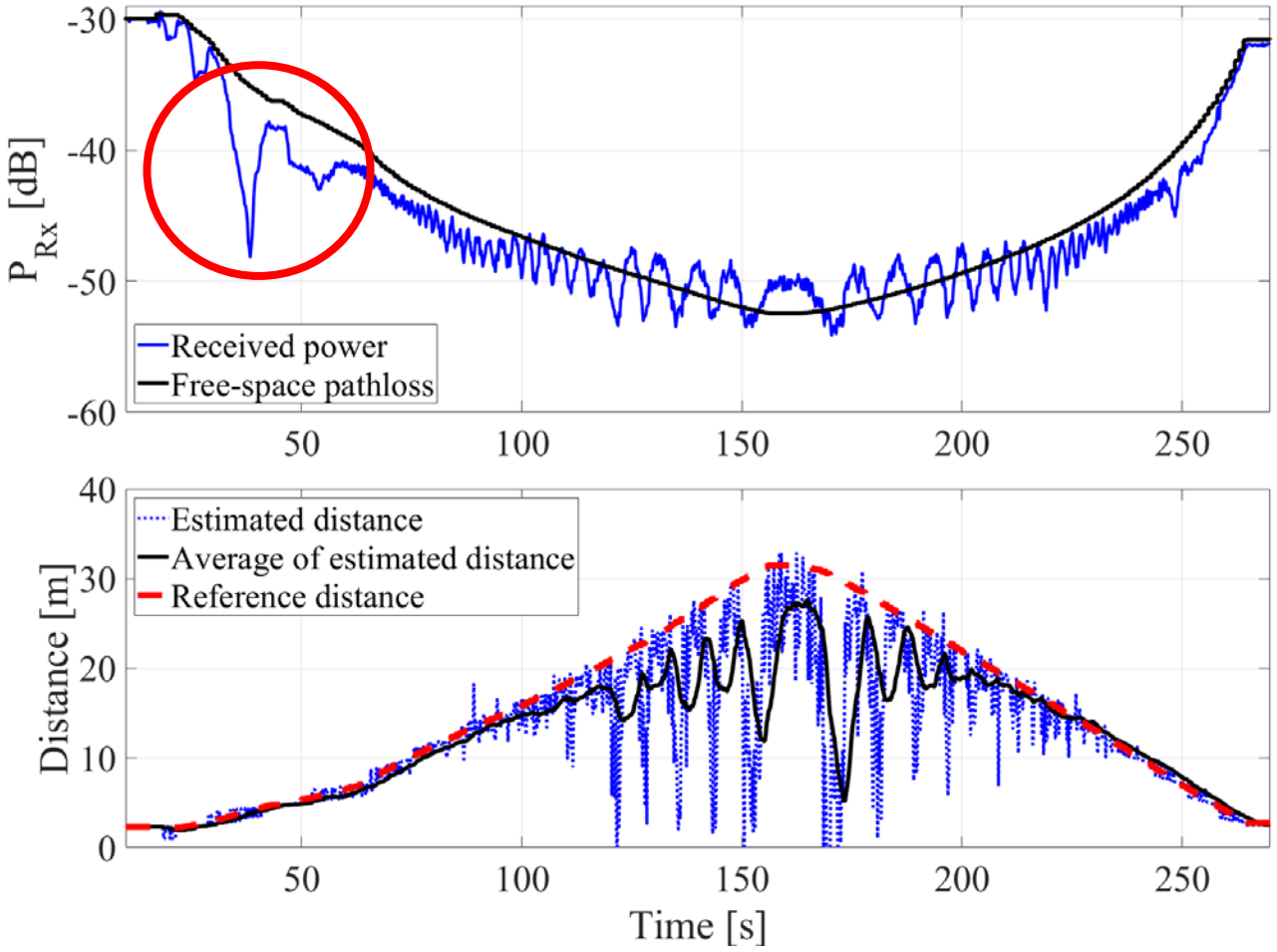


Automatic Coupling: Parking Lot, Dynamic Measurements



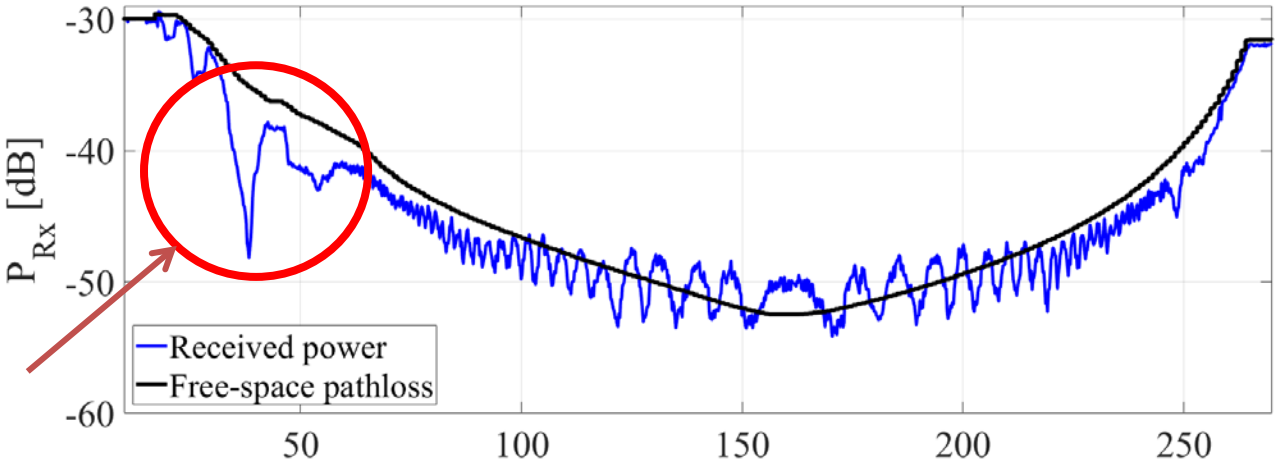
Automatic Coupling: Parking Lot, Dynamic Measurements

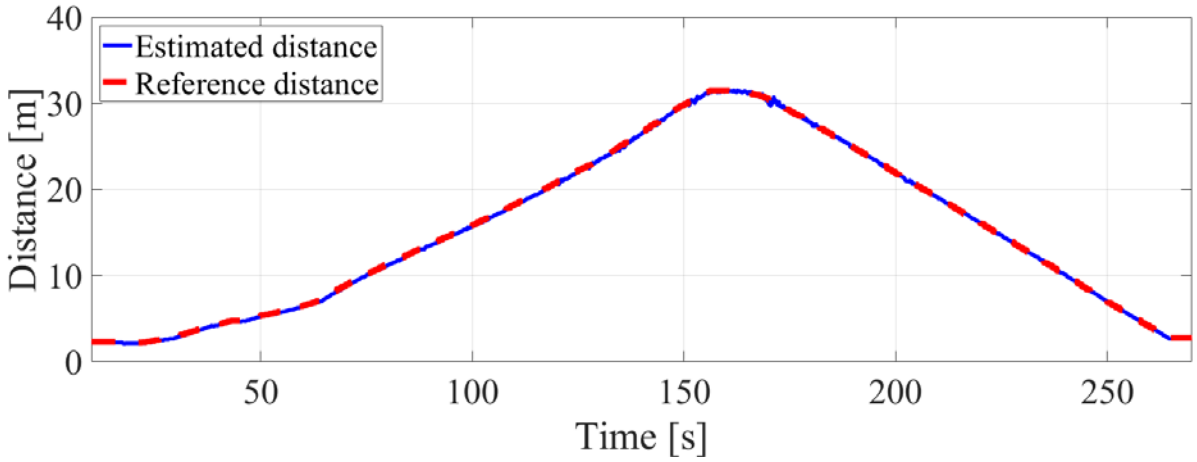
Automatic Coupling: Parking Lot, Dynamic Measurements, Preliminary Results



Automatic Coupling: Parking Lot, Dynamic Measurements, Preliminary Results

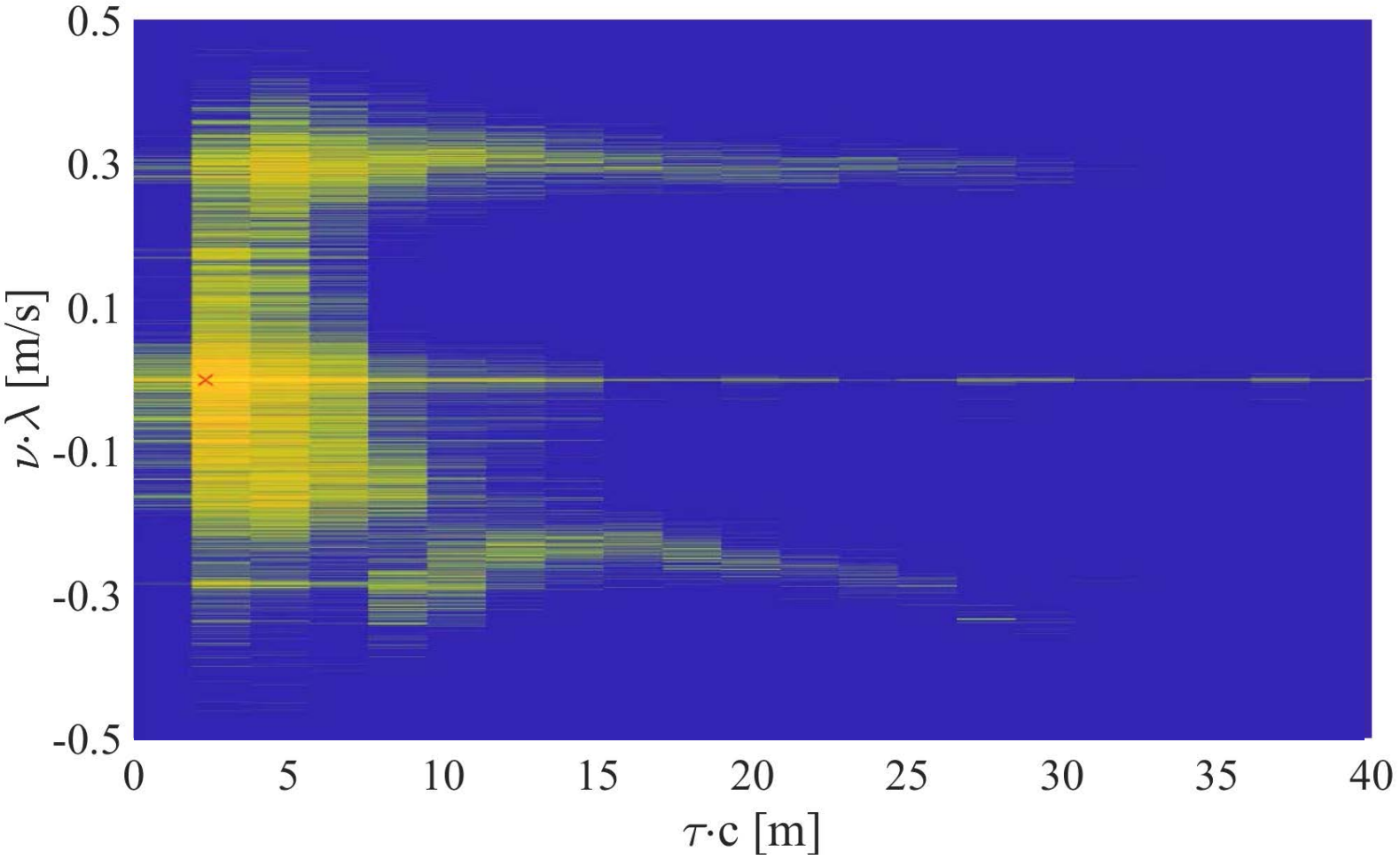
Received power drop due to misalignment



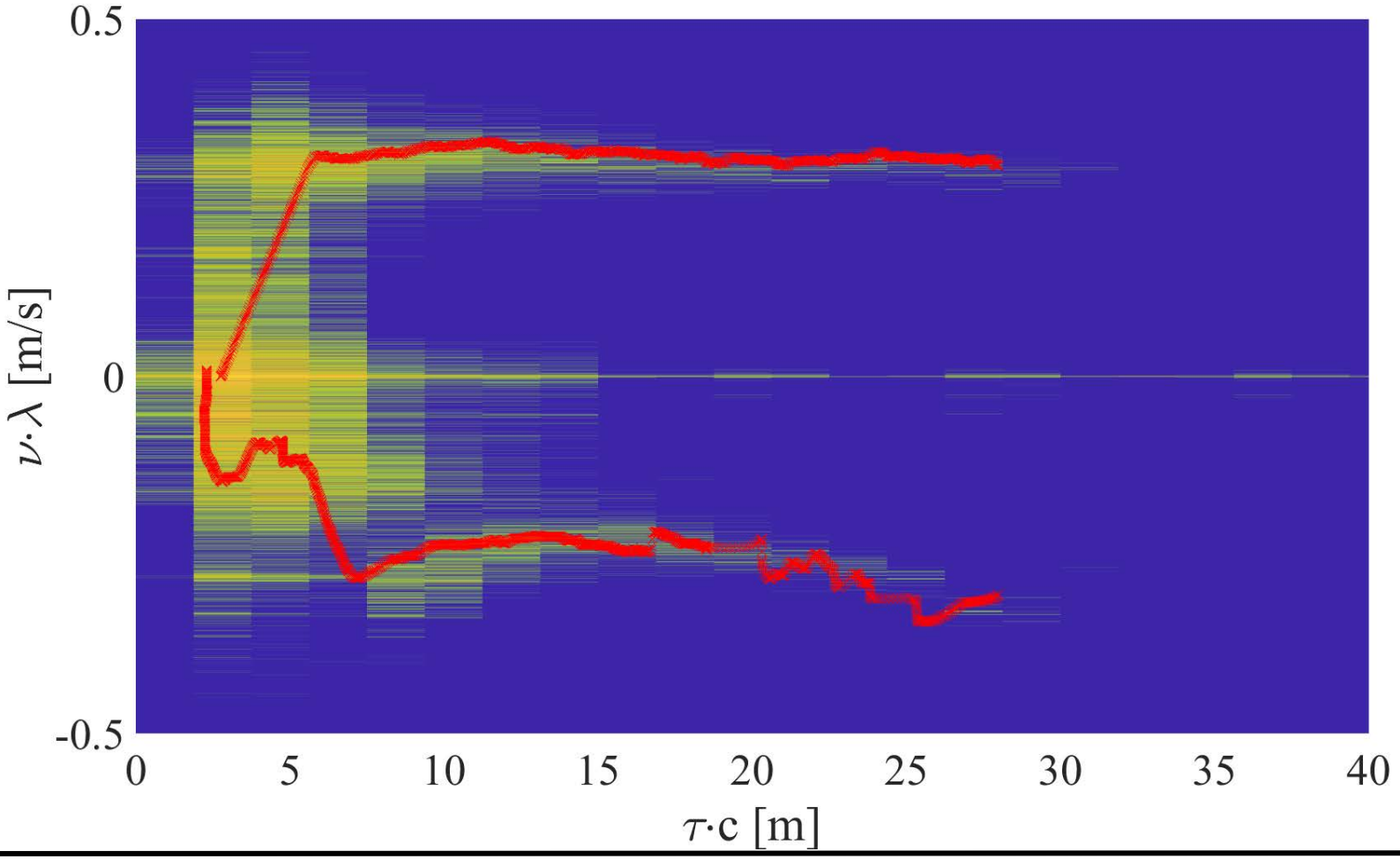


99% of errors < 0.3 m

Automatic Coupling: Parking Lot, Dynamic Measurements, Preliminary Results

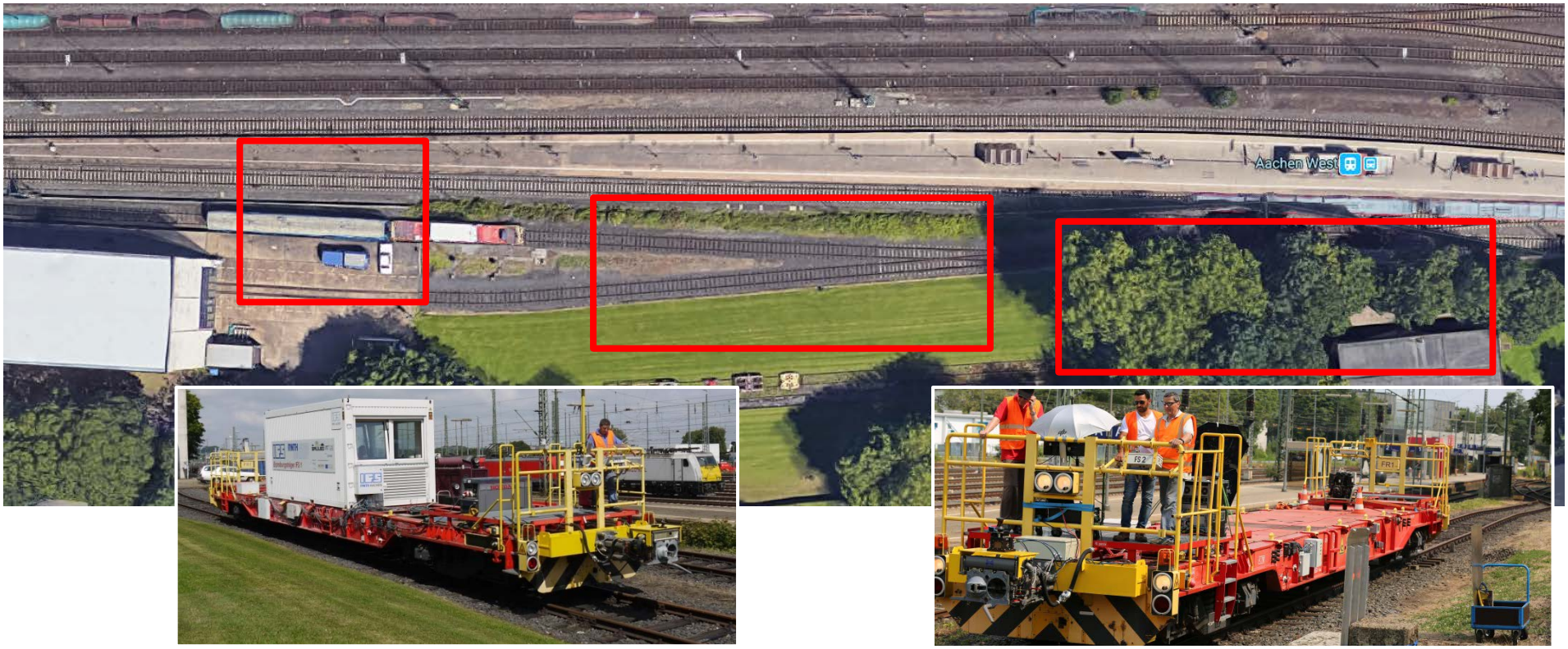


Automatic Coupling: Parking Lot, Dynamic Measurements, Preliminary Results



Automatic Coupling: Measurement Campaign

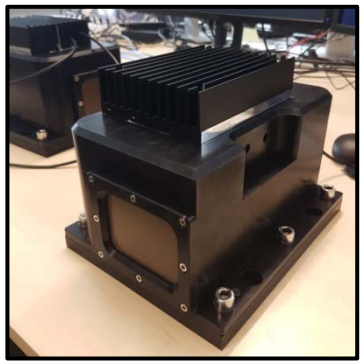
- Department of Rail Vehicles and Transport Systems (IFS) RWTH Aachen
- 300 m long track, 2 experimental trains



Automatic Coupling: Measurement Campaign

Automatic Coupling: Measurement Campaign

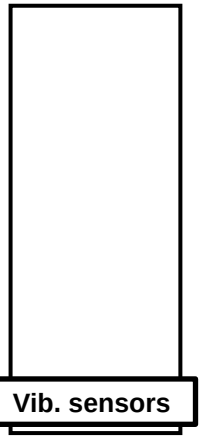
- 1 day of measurements (24 July)
- Up to three runs per environment (38 runs in total):
  - Open field
  - Platform
  - 1 metallic sheet
  - 2 metallic sheets
  - Bushes and trees
  - Train driving in a parallel track
- Up to 130 m separation between the trains
- Relative speed up to 5 km/h



mmWave frontends

Channel sounder

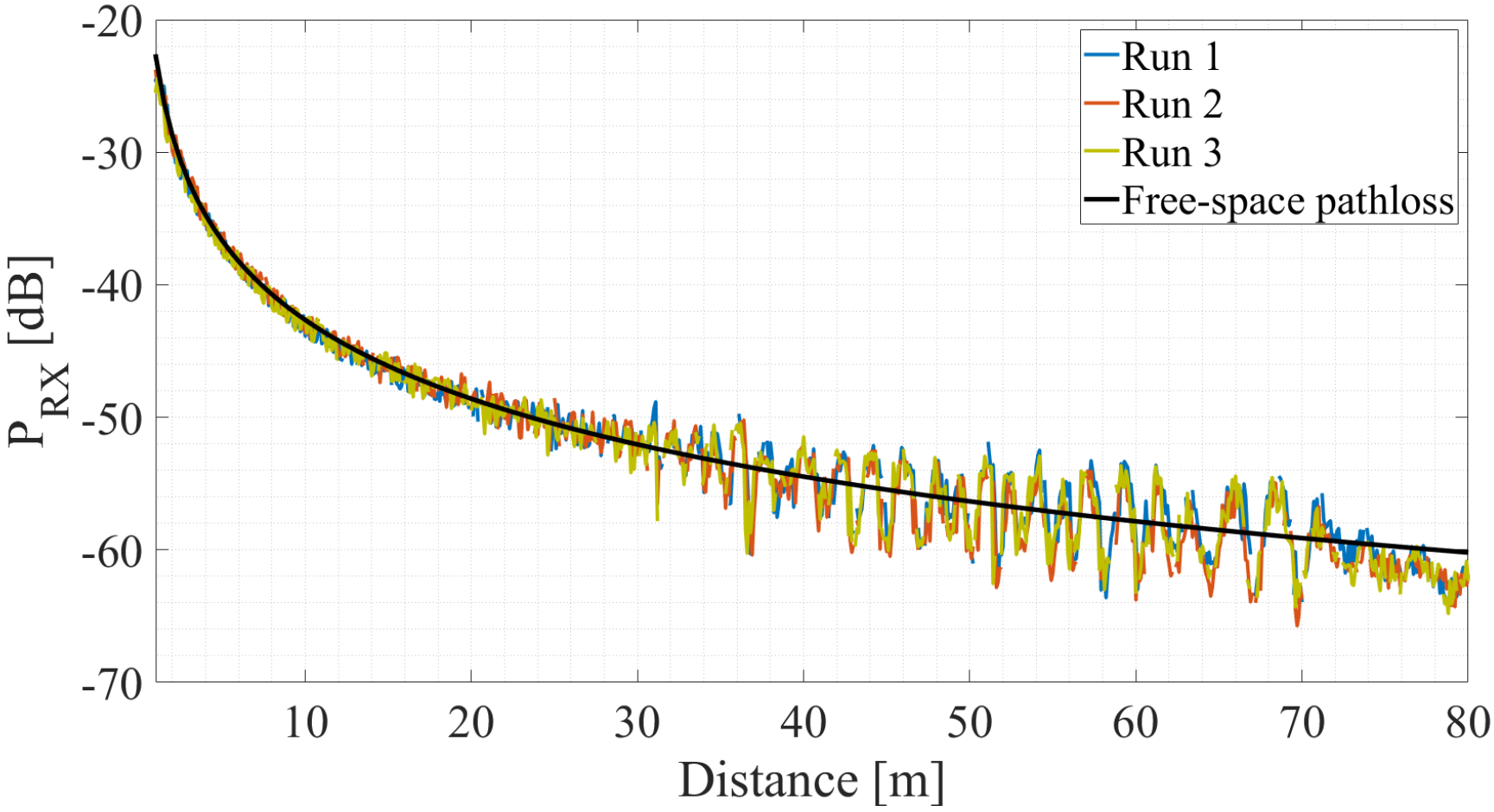
NI USRP



Vib. sensors

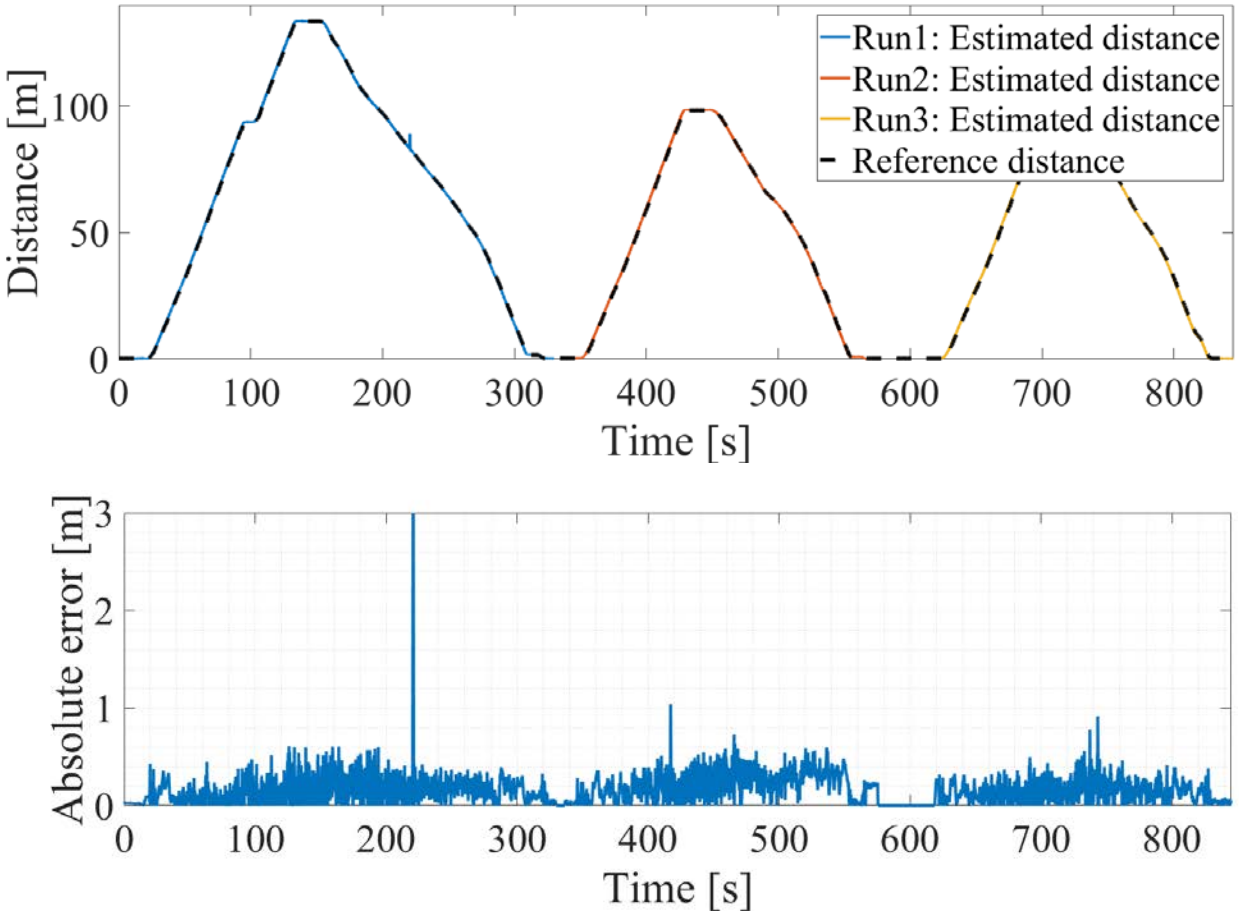
Reference systems

Automatic Coupling: Measurement Campaign Measured Received Power – Open Field



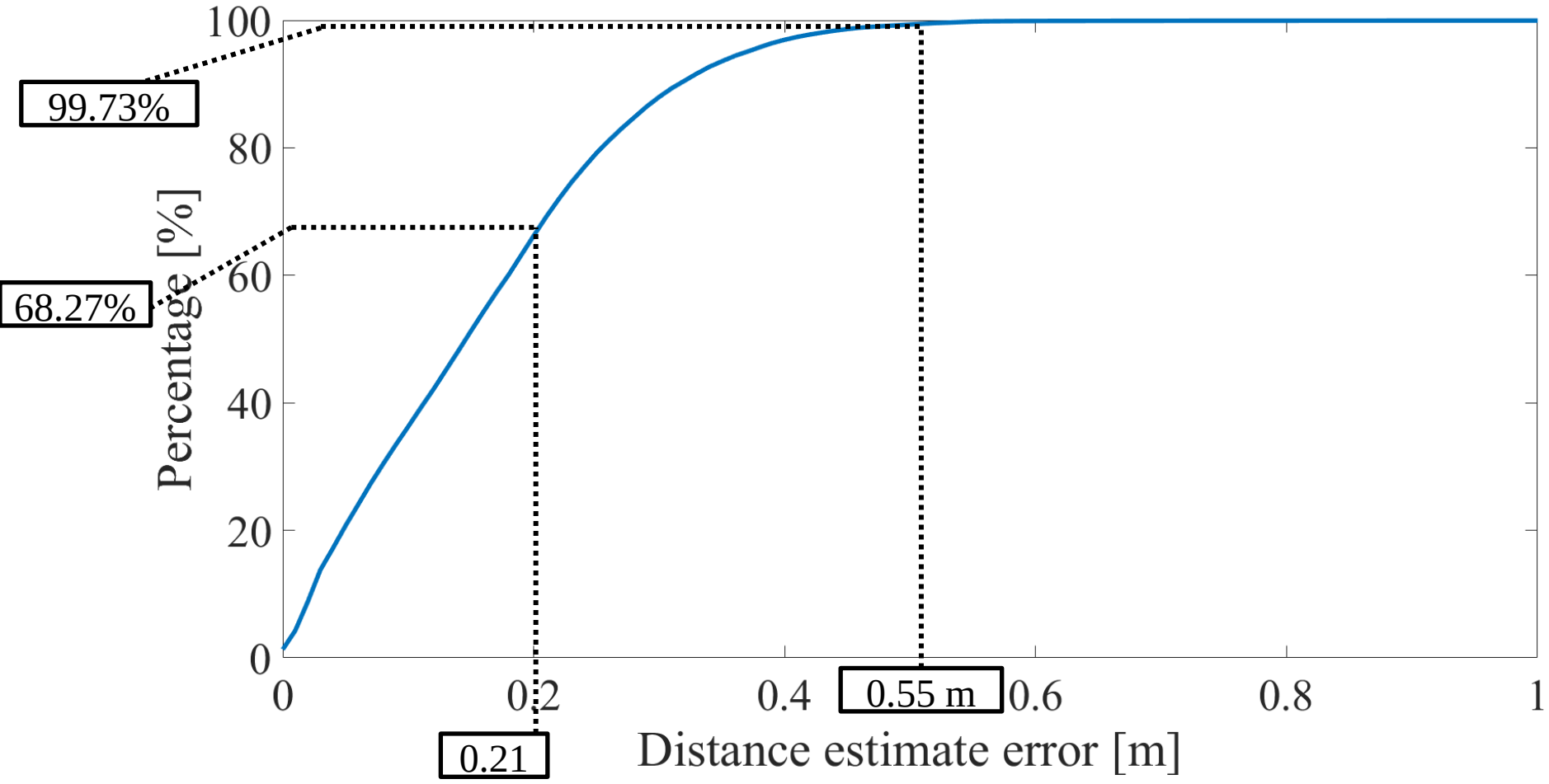
Automatic Coupling: Measurement Campaign

Measured Ranging Accuracy – Distance Estimation Error



Automatic Coupling: Measurement Campaign

Measured Ranging Accuracy –Errors CDF



Automatic Coupling: Measurement Campaign

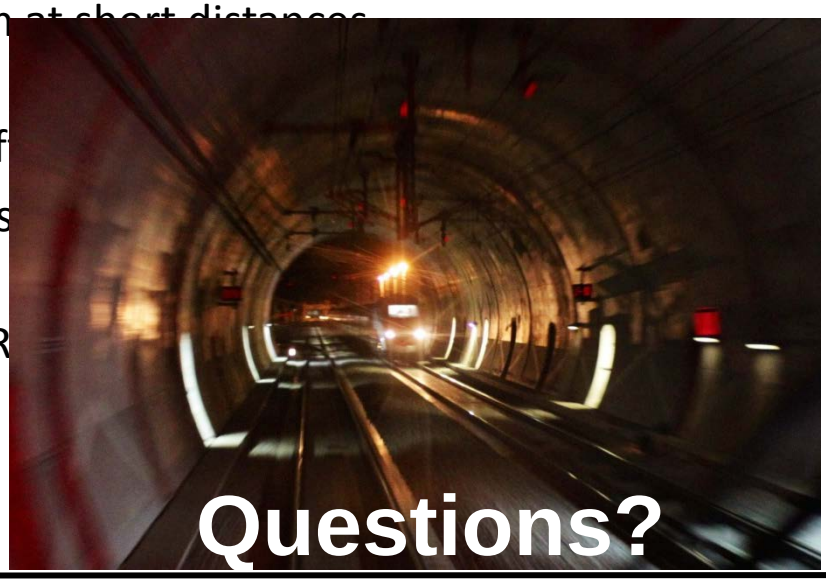
Special Thanks to Team!

Summary and Conclusions

- mmWave channel sounder for dynamic measurements
  - Mean receive power ~ free space path loss & 15 dB above noise floor @ 110 m
  - Highly directive antennas: Multipath propagation
- Example automatic coupling
  - mmWave URLLC&R for automatic approach and train integrity monitoring
  - Best ranging accuracy for mmWave system at short distances, only slightly worse for severe rain
- New railway applications to further increase efficiency and flexibility
  - Wireless TCMS, autonomous trains & collision avoidance, automatic coupling, virtual coupling
  - 5G URLL communication and ranging (C&R) essential for enabling new safety relevant railway applications

Summary and Conclusions

- mmWave channel sounder for dynamic measurements
  - Mean receive power ~ free space path loss & 15 dB above noise floor @ 110 m
  - Highly directive antennas: Multipath propagation
- Example automatic coupling
  - mmWave URLLC&R for automatic approach and train integrity monitoring
  - Best ranging accuracy for mmWave system at short distances, only slightly worse for severe rain
- New railway applications to further increase ef
  - Wireless TCMS, autonomous trains & collis automatic coupling, virtual coupling
  - 5G URLL communication and ranging (C&R relevant railway applications



Papers & References

1. Souce wikipedia https://commons.wikimedia.org/wiki/File:Autobahn_A8_bei_Holzkirchen.JPG
2. Source wikipedia https://commons.wikimedia.org/wiki/File:Gleise_zu_Z%C3%BCrich_HB_2010.jpg
3. Source wikipedia https://en.wikipedia.org/wiki/Autonomous_car#/media/File:Tesla_Autopilot_Engaged_in_Model_X.jpg
4. Source Ministerie van Infrastructuuur en Milieu, ITS in the Netherlands Progress Report 2014 – 2017, July 2017. https://www.connekt.nl/wp-content/uploads/2017/12/20170905-ITS-Netherlands-Progress-Report-2017_def.pdf
5. Source wikipedia https://en.wikipedia.org/wiki/File:ETCS_L2_en.svg
6. Source wikipedia https://en.wikipedia.org/wiki/File:ETCS_L3_en.svg
7. Source CONNECTA Report Summary https://cordis.europa.eu/result/rcn/200968_en.html

Papers & References

8. Lehner, Andreas und Rico Gracía, Cristina und Strang, Thomas (2011) A multi-broadcast communication system for high dynamic vehicular ad-hoc networks. International Journal of Vehicle Information and Communication Systems, Vol. 2 (No. 3/4), Seiten 286-302, Inderscience Publishers, DOI: 10.1504/IJVICS.2011.044267, ISSN 1471-0242. https://www.inderscienceonline.com/doi/pdf/10.1504/IJVICS.2011.044267
9. Soliman, Mohammad und Sand, Stephan und Schmidhammer, Martin und Staudinger, Emanuel (2017) *Effect of Non-Integer Delay on Ranging Accuracy for Ultra-Reliable Systems.* ICL GNSS 2017, 27-29 June 2017, Nottingham, England. http://elib.dlr.de/114201/
10. Unterhuber, Paul und Sand, Stephan und Soliman, Mohammad und Siebler, Benjamin und Lehner, Andreas und Strang, Thomas und Gera, Damini (2017) *Wide Band Propagation in Train-to-Train Scenarios - Measurement Campaign and First Results.* EUCAP 2017, 19.-24.März 2017, Paris, Frankreich. http://elib.dlr.de/111876/
11. SBDist project http://industrialradio.de/Projects/Home/SBDist

Papers & References

12. Soliman, Mohammad and Unterhuber, Paul and De Ponte Müller, Fabian and Schmidhammer, Martin and Sand, Stephan and Dekorsy, Armin (2018) Design and Evaluation of a Millimeter Wave Channel Sounder for Dynamic Propagation Measurements. VTC Fall 2018, 27-30 Aug 2018, Chicago, USA. http://elib.dlr.de/120663
13. Walter, Michael und Fiebig, U.-C. und Zajic, Alenka (2014) Experimental Verification of the Non-Stationary Statistical Model for V2V Scatter Channels. In: 2014 IEEE 80th Vehicular Technology Conference (VTC Fall). IEEE. 2014 IEEE 80th Vehicular Technology Conference, 14.-17. Sep. 2014, Vancouver, Kanada. DOI: 10.1109/VTCFall.2014.6965981 ISSN 1090-3038. https://elib.dlr.de/89609/
14. Wang, Wei und Jost, Thomas und Raulefs, Ronald und Fiebig, Uwe-Carsten (2017) Ship-to-ship broadband channel measurement at 5.2 GHz on north sea. In: The 11th European Conference on Antennas and Propagation. The 11th European Conference on Antennas and Propagation, March 2017, Paris, France. https://elib.dlr.de/109204/