Communication in the Delay Doppler Domain

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What is OTFS

- Paradigm of communication in the delay-Doppler Domain:

- Model and process the wireless channel in the delay-Doppler domain
  - Delay-Doppler channel representation

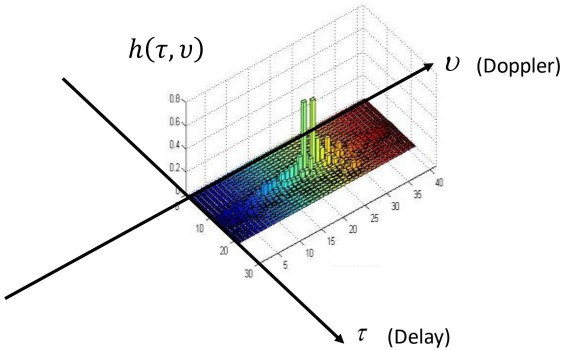
- Multiplex information in the delay-Doppler domain
  - OTFS modulation/waveform

- Mathematical unification of communication and radar theory
  - Framework for joint communication and sensing

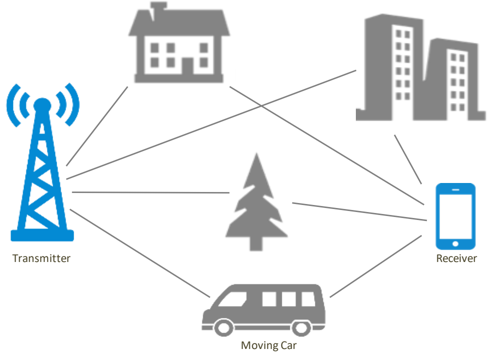
(*) More than 300 scientific publications on OTFS

The delay-Doppler Channel Representation

Delay-Doppler Channel Representation



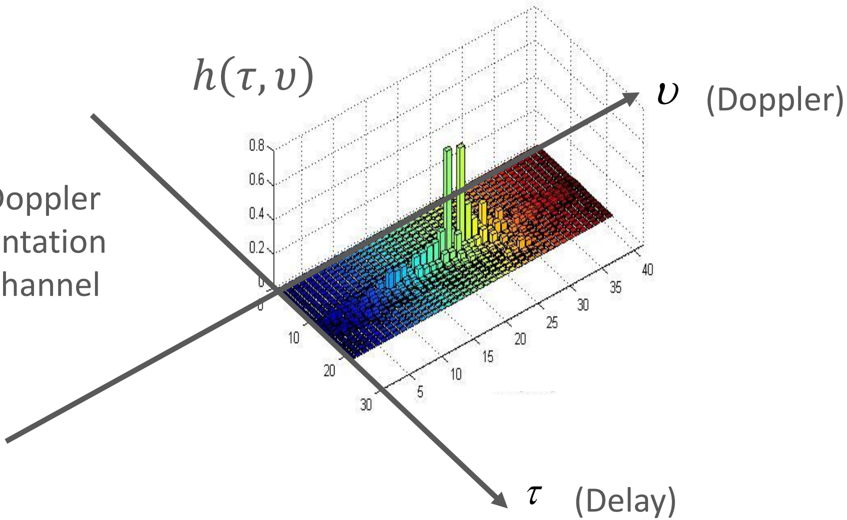
Multipath Geometric Representation
(Distance, Speed & Direction)



ADVANTAGES

- Reduces channel dimensionality
  - Efficient channel acquisition
  - Efficient channel prediction
  - Efficient channel equalization

The delay-Doppler Channel Representation



The sparsest representation of the wireless channel

Main observation: the wireless channel is governed by stationary parameters:

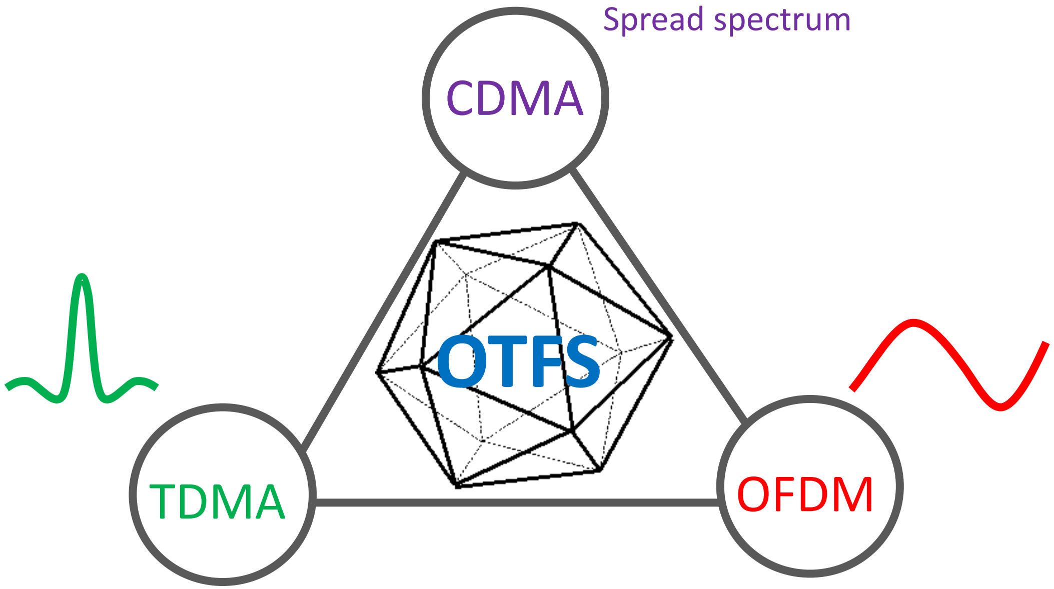
- Reflector delay: $\tau = \frac{\text{range}}{c}$
- Reflector Doppler: $\nu = f \cdot \frac{\text{velocity}}{c}$
- Reflector propagation loss:

$$h = e^{j2\pi\theta} \times r$$

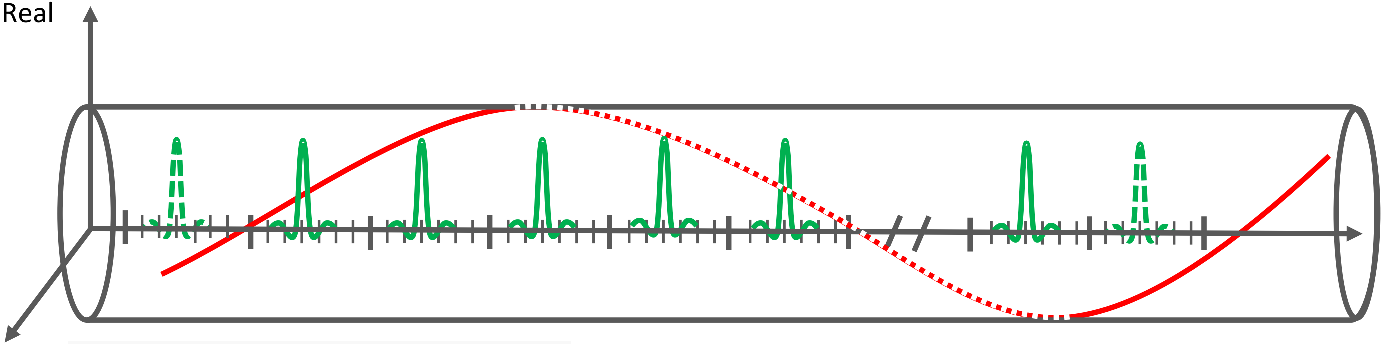
- $\{\tau, \nu, r\}$ change slowly in time and independent of carrier frequency

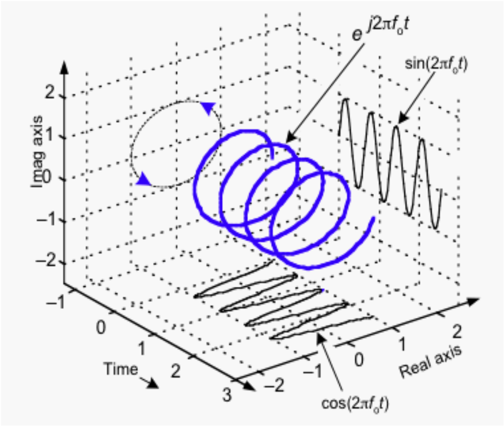
INFORMATION MULTIPLEXING IN DELAY-DOPPLER
THE OTFS MODULATION

The Mother Waveform



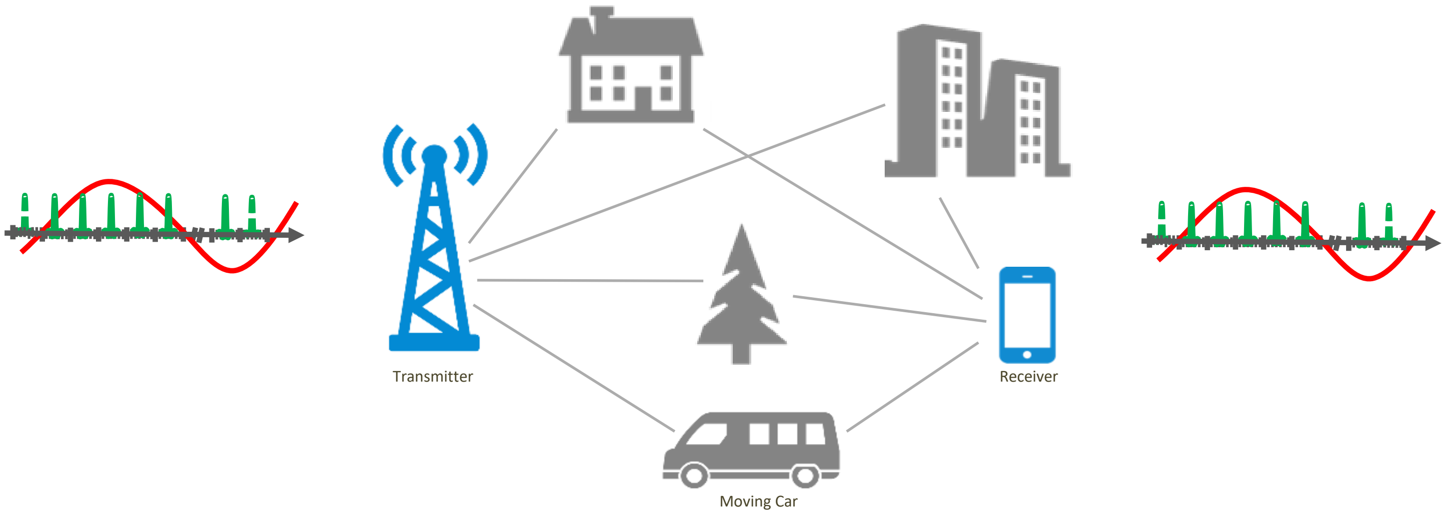
The OTFS Waveform Carrier: Pulsone





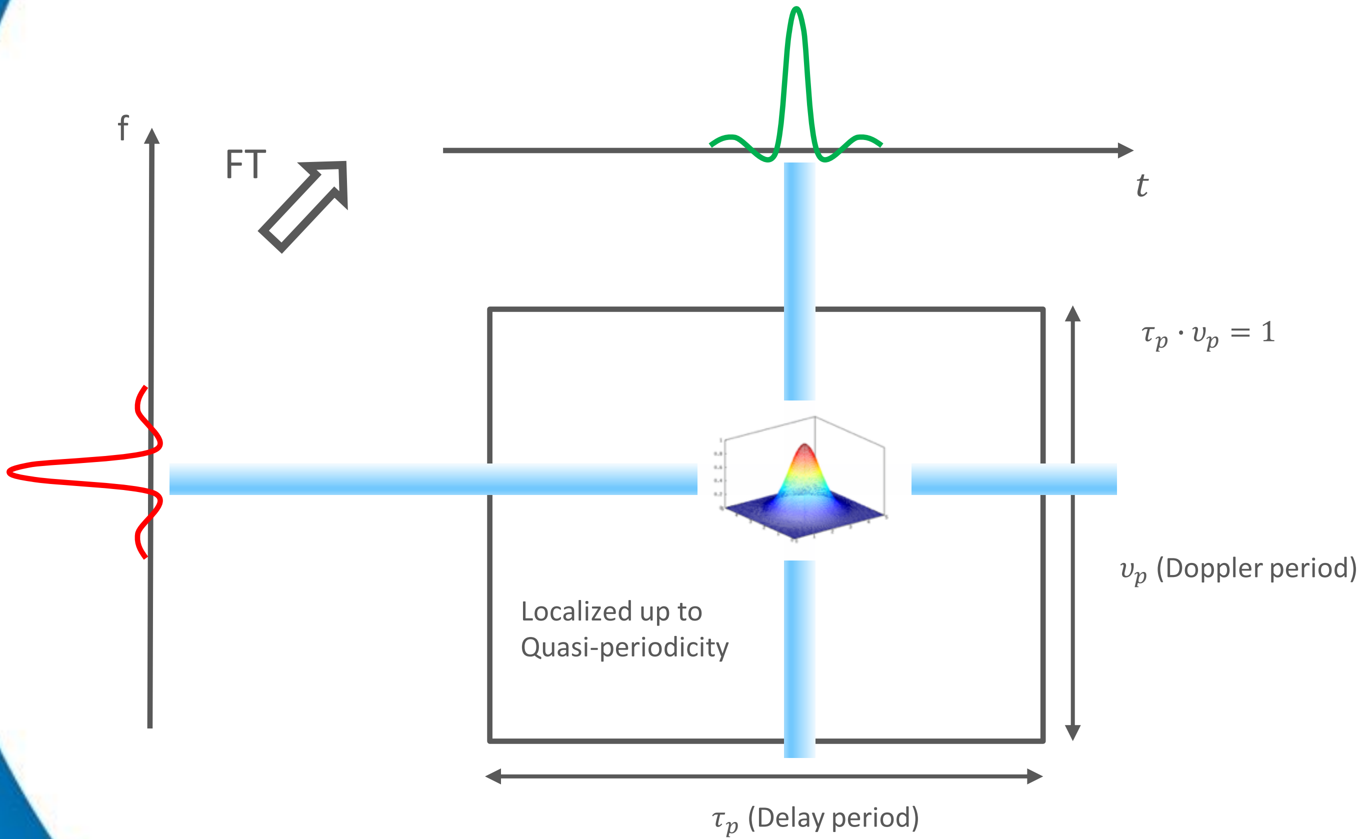
The pulsone remains invariant under the operations of time delay and Doppler shift

Invariance to Channel Conditions

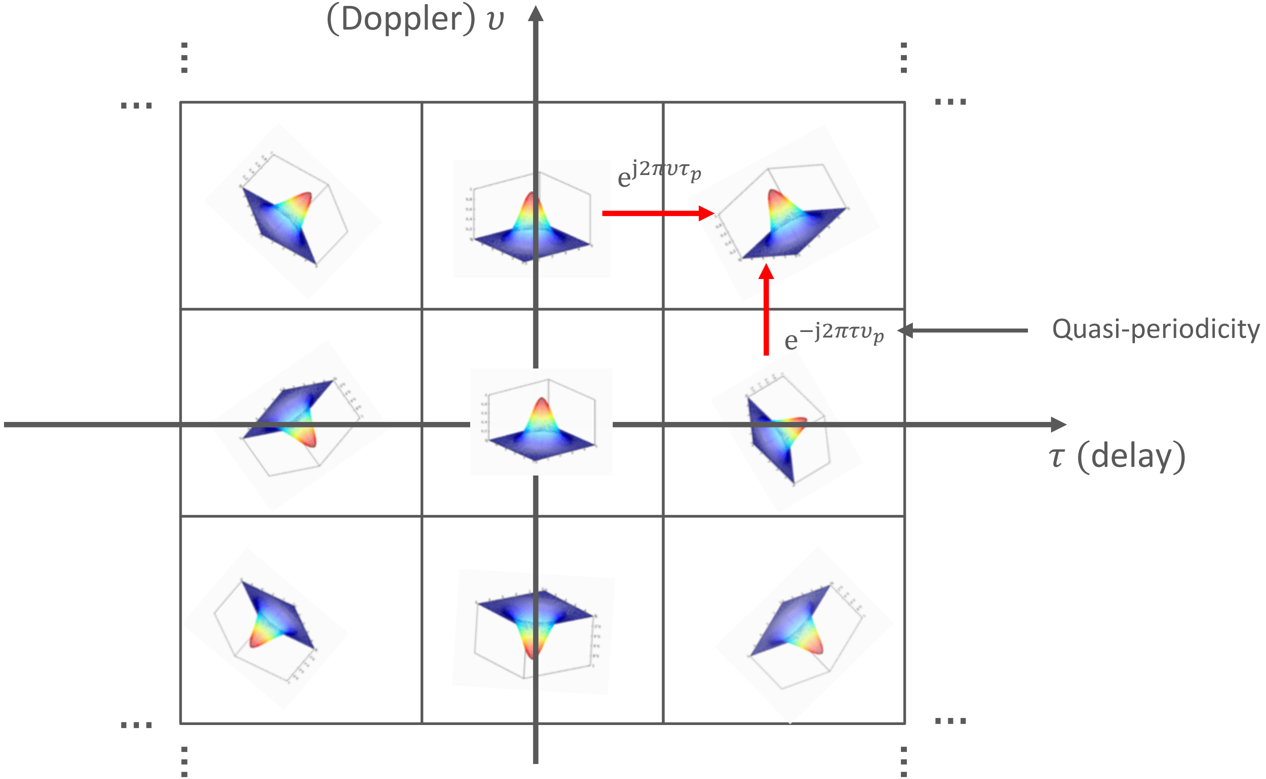


performance consistency and robustness under all channel conditions

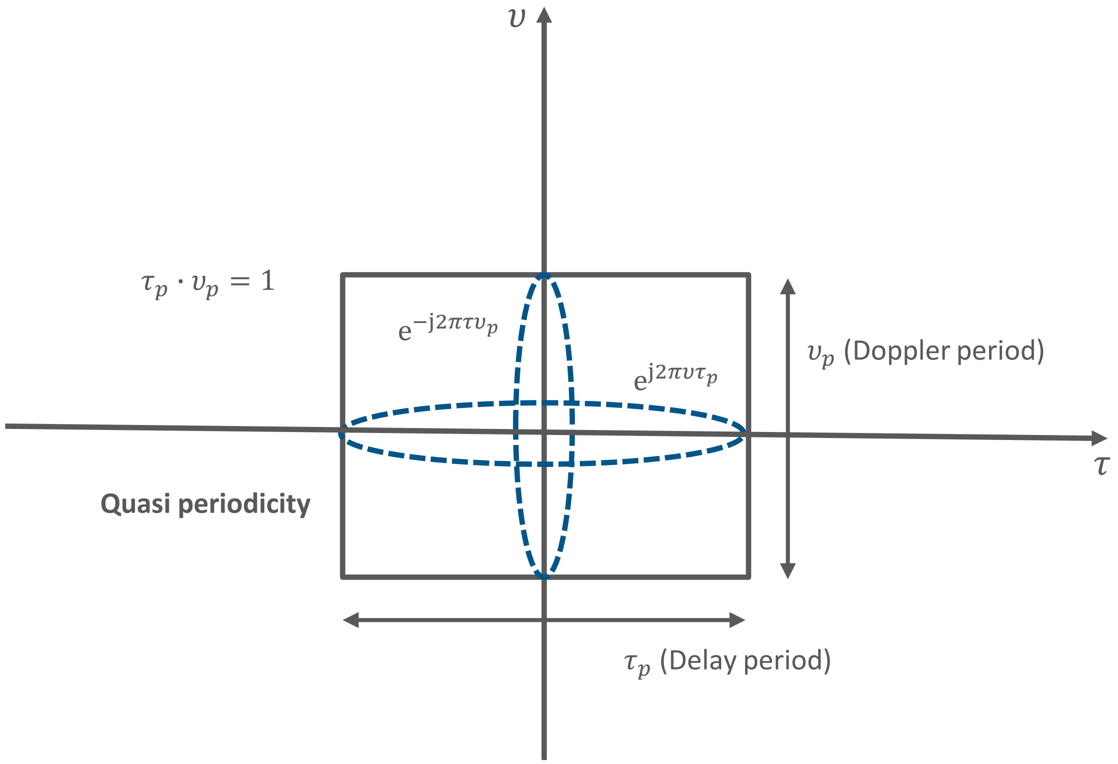
The Mathematics of the pulsone



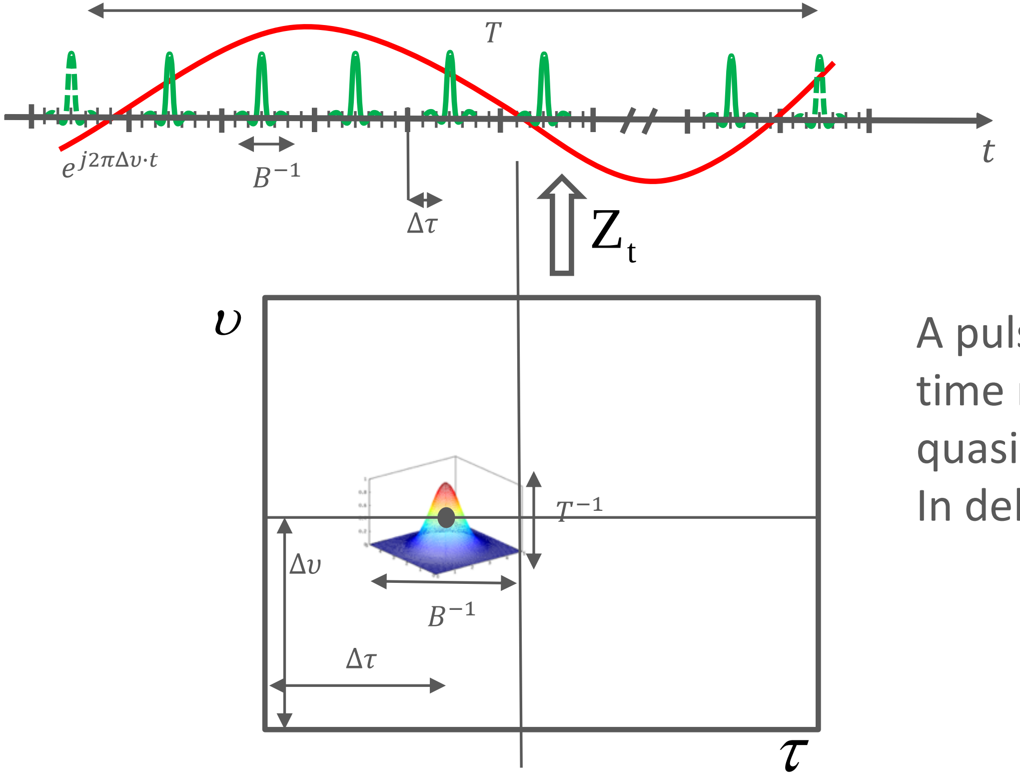
Quasi-Periodic Extension



The delay-Doppler (quasi-periodic) Signal Representation

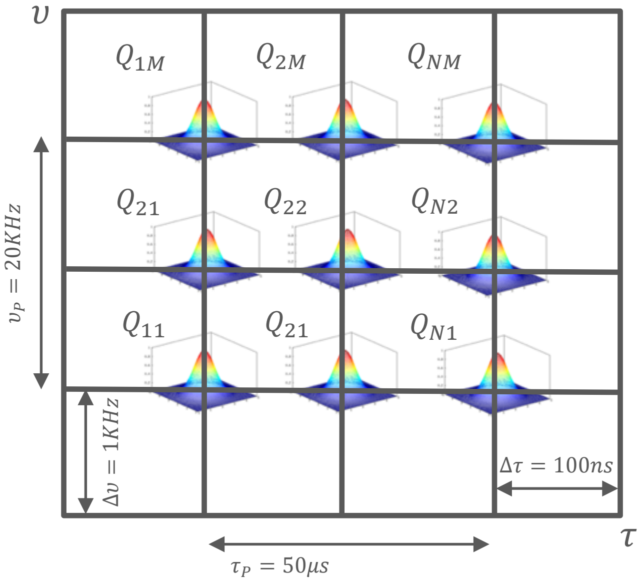


The OTFS Pulsone Revisited



A pulsone is the time realization of a quasi-periodic pulse In delay-Doppler

OTFS Packet Structure and Numerology



$$B = \frac{1}{100ns} = 10Mhz$$

$$T = \frac{1}{1KHz} = 1ms$$

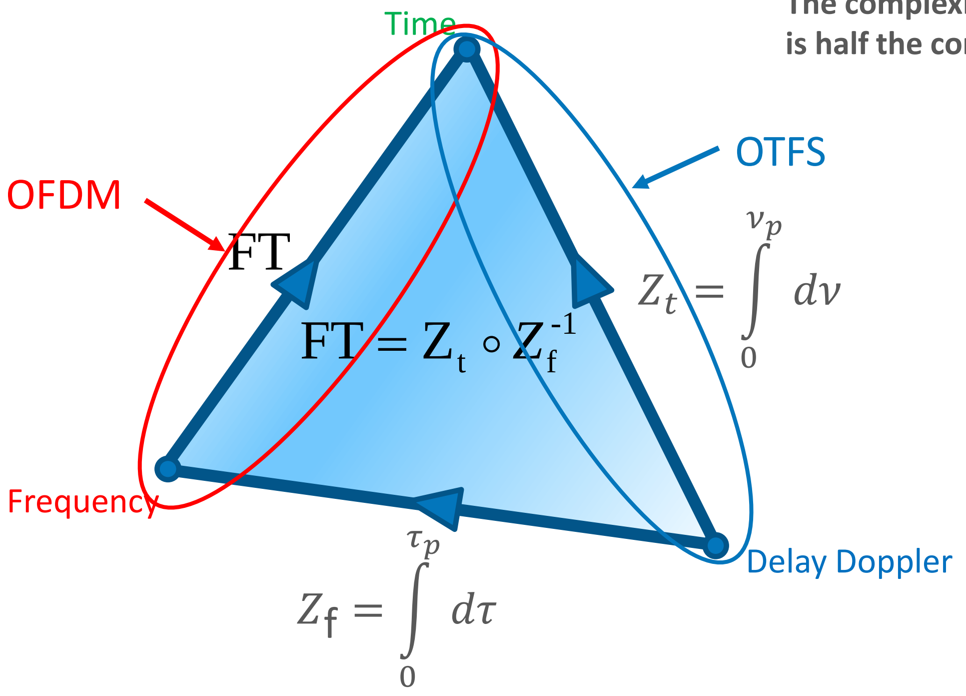
$$N = \frac{50\mu s}{100ns} = 500$$

$$M = \frac{20KHz}{1KHz} = 20$$

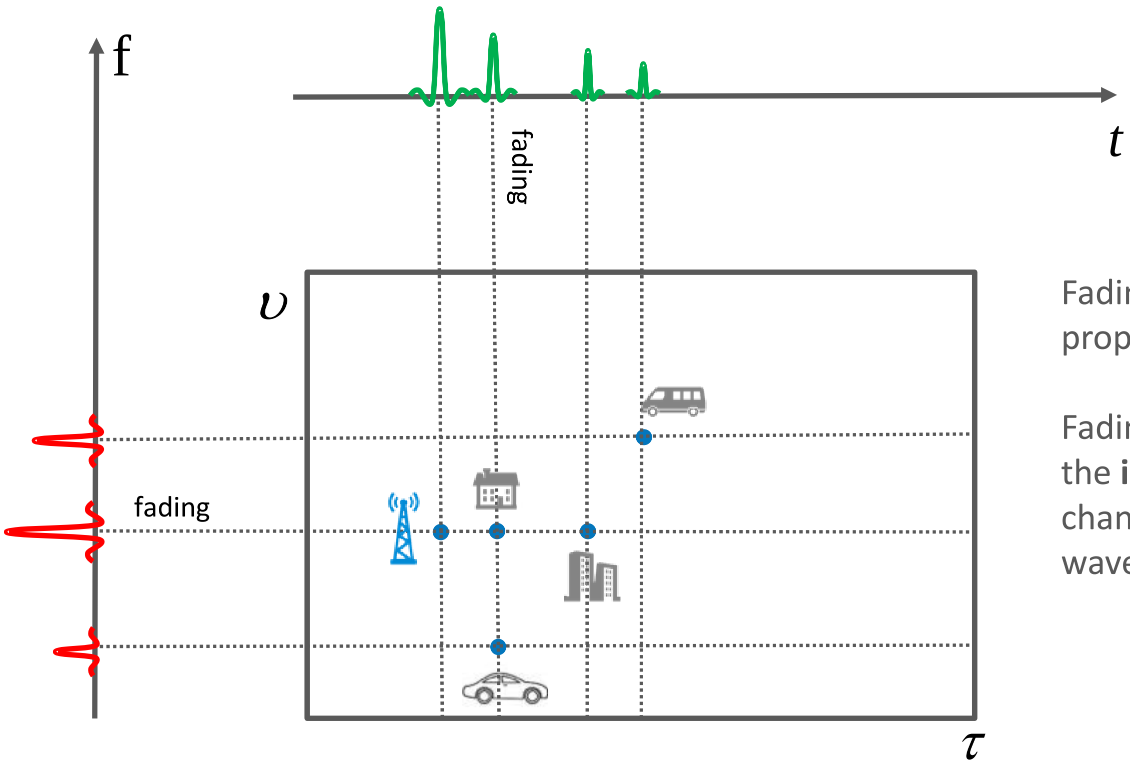
Signal Processing Revisited

Three Fundamental Signal Representations

The complexity of the Zak transform is half the complexity of the FFT



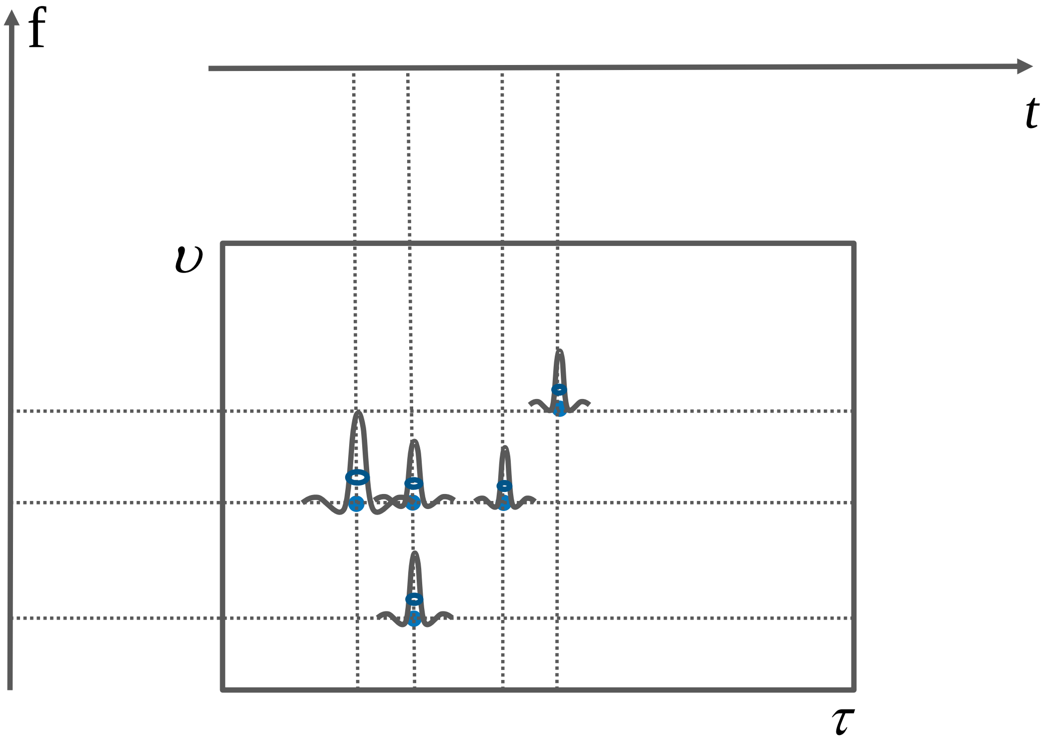
Time-Frequency Localization through Channel Coupling



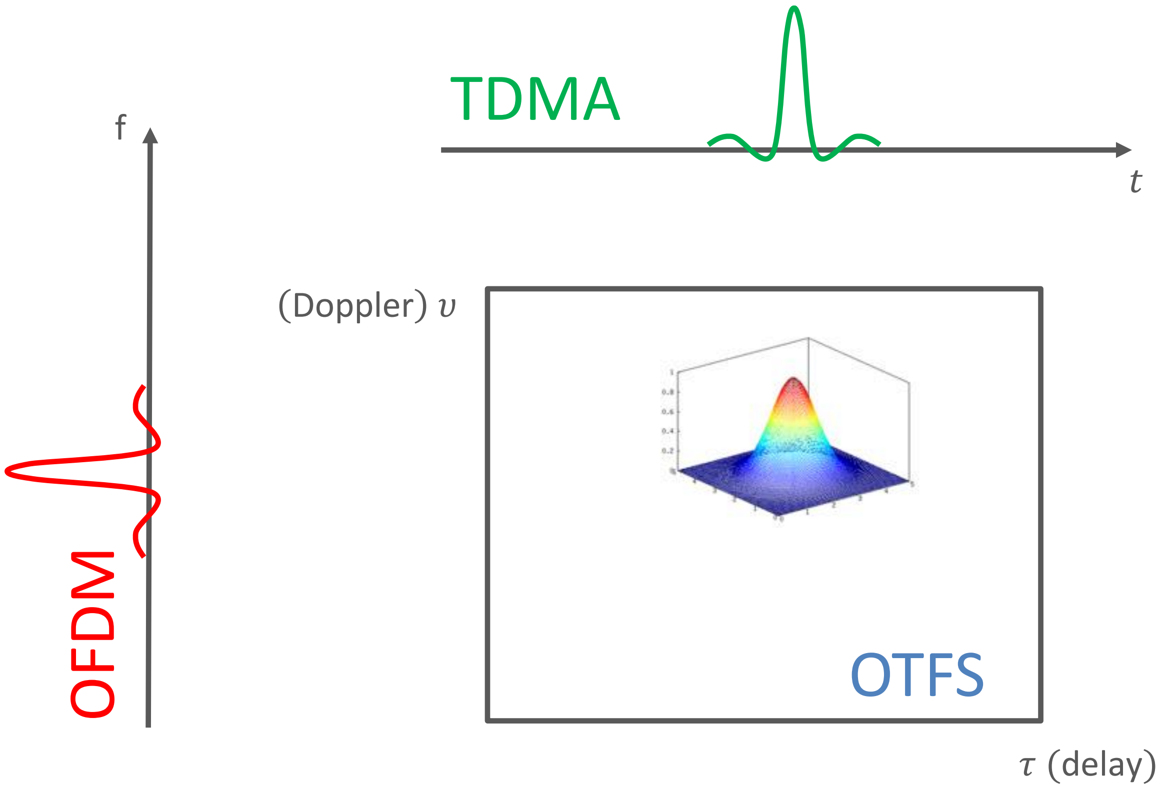
Fading is **NOT** an intrinsic property of the channel

Fading is an attribute of the **interaction** of the channel with a specific waveform

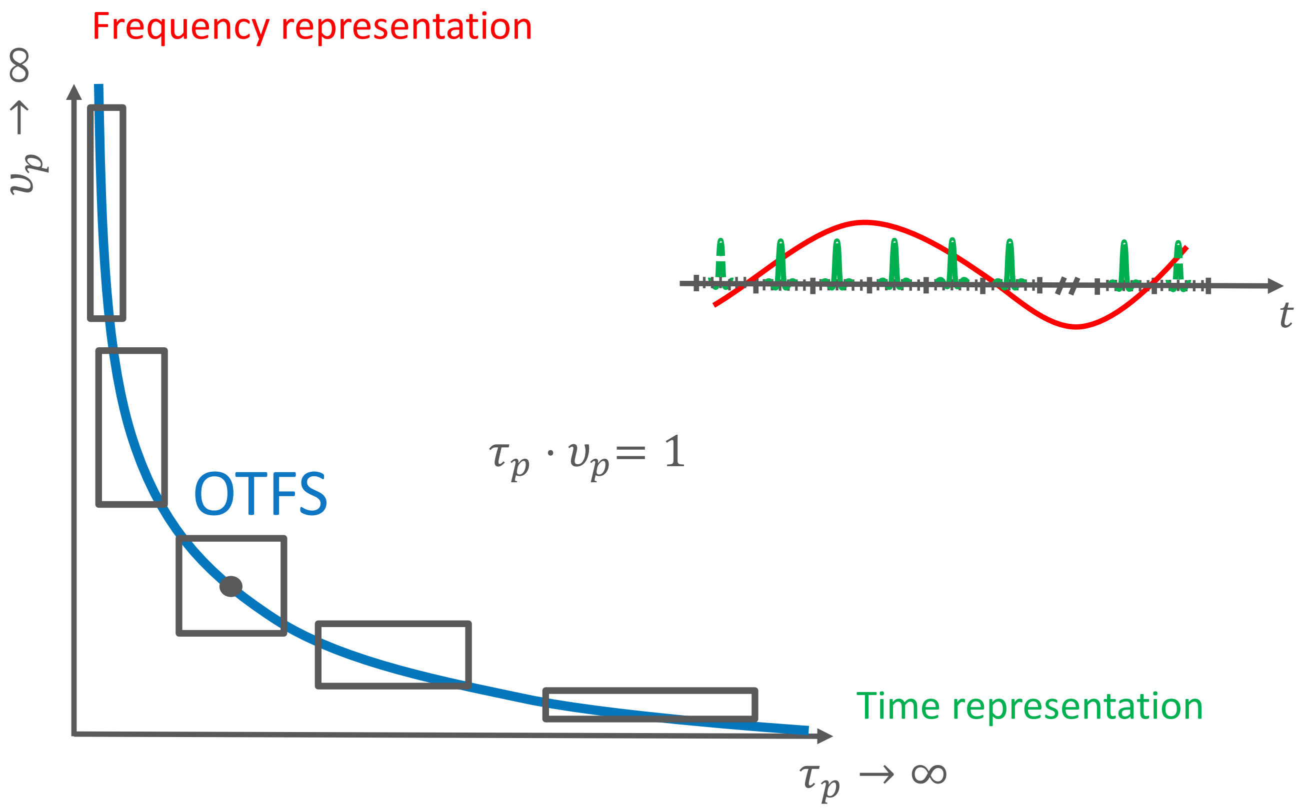
The OTFS Channel Coupling



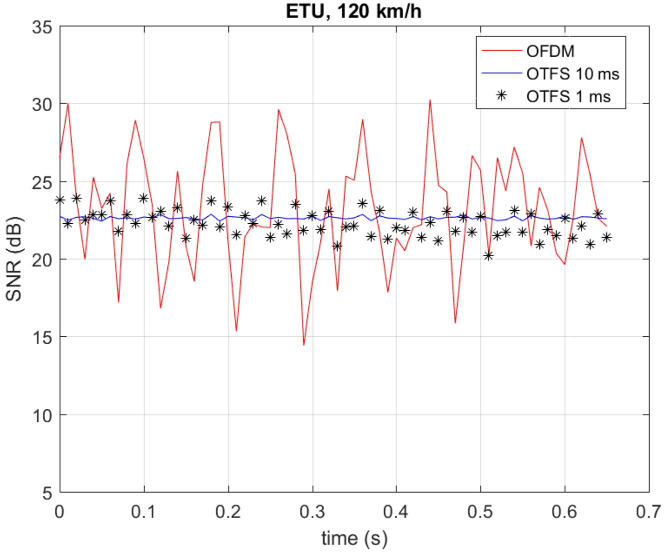
Communication Theory Revisited

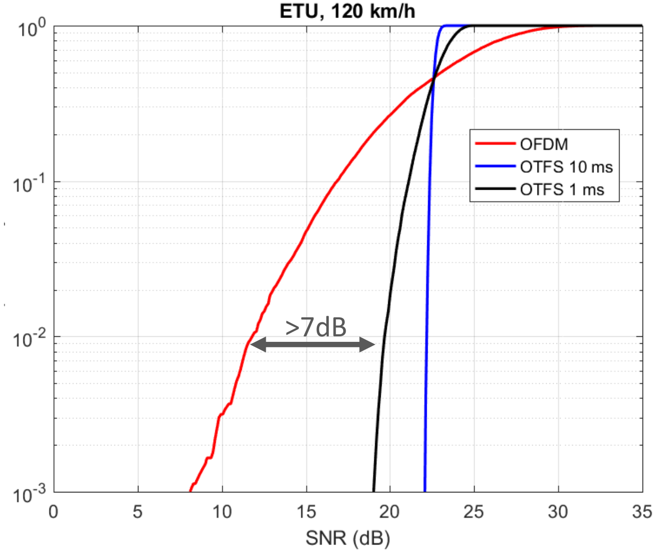


OTFS Universality

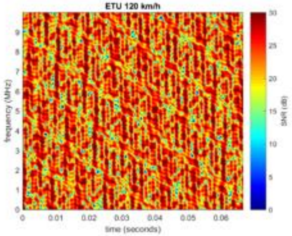


SNR Distribution Comparison



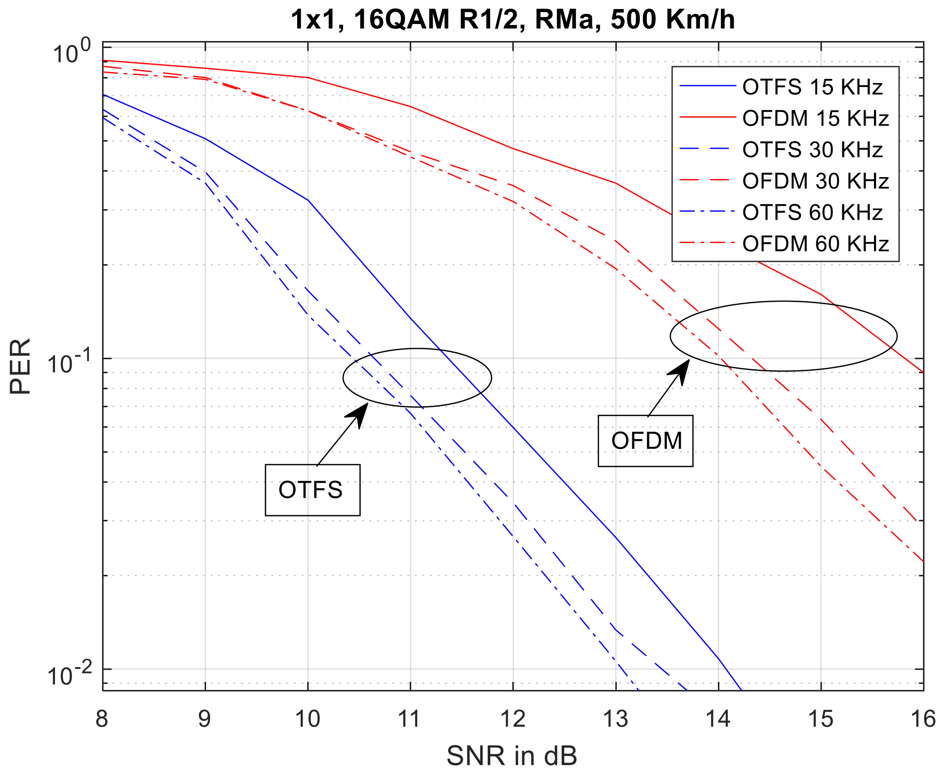


Modulation	Min SNR	Max SNR	σ
OFDM	5.00	32.76	4.25
OTFS 1 ms	18.70	24.99	1.10
OTFS 10 ms	22.00	23.36	0.22



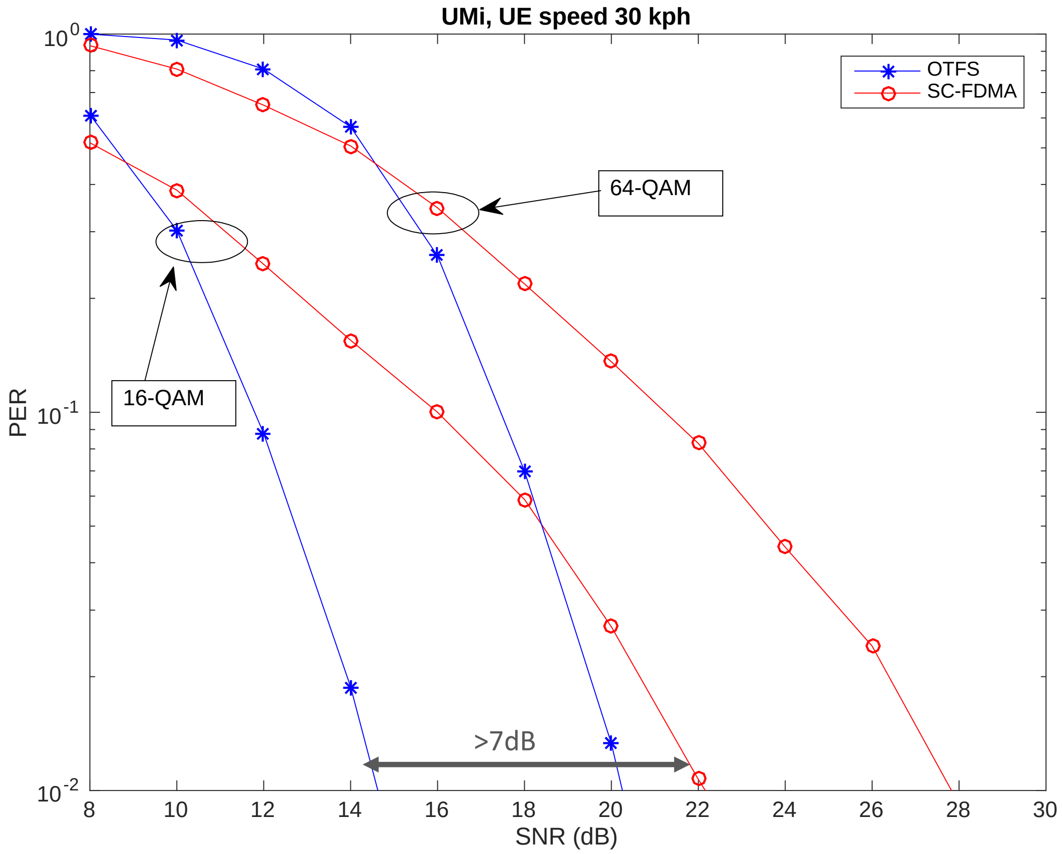
OTFS is Resilient to Inter Carrier Interference (ICI)

- OTFS 15 kHz outperforms OFDM 60 kHz



SC-OTFS Performance Gain Compared to SC-FDMA

- OTFS Achieves SC PAPR while extracting full time and frequency channel diversity



OTFS Advantages

- Resilience to delay and Doppler spread
  - No cyclic prefix overhead
  - No inter carrier interference
  - Full channel diversity
  - Efficient pilot structure (independent of # coherence time intervals)

- Spread spectrum
  - Processing gain
  - Security communication

- Joint communication transceiver and radar sensing

THANK YOU