

# Fractional Fourier Transform Based Co-Radar Waveform: Experimental Validation

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CeSIP

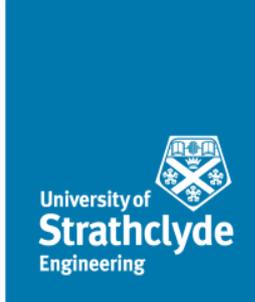
Centre for Signal and Image Processing



SSPD  
Conference

# Outline

- **Joint Radar-Communication Systems**
- **FrFT Based Co-Radar**
  - Waveform Design
  - Comparison with OFDM
- **Experimental Validation**
  - Equipment
  - Setup
  - Implementation
  - Results
- **Conclusions**



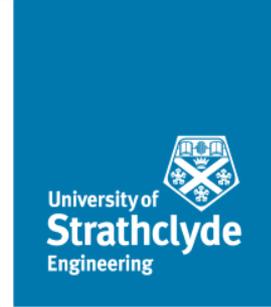
# Joint Radar-Comms Systems

In some scenarios there is the **dual need** for a system to perform **radar operations** (target detection and classification, velocity estimation, imaging, etc.) while **sending data** to another cooperative system, i.e.:

- Nodes in a Surveillance Multiple-Input Multiple-Output (MIMO) Radar Network;
- Satellite/Airborne Synthetic Aperture Radar (SAR) and a Ground Base Station;
- Vehicles in an Intelligent Transportation System (ITS).

## Possible Solutions:

- Use of a Secondary Communication System
  - ✗ Overhead of resources allocation
- Switch Between Radar and Communication Operations
  - ✓ Resources sharing
  - ✗ Not continuous radar operation
- Embedding Data in the Radar Waveform
  - ✓ Resources sharing
  - ✓ Continuous radar operation

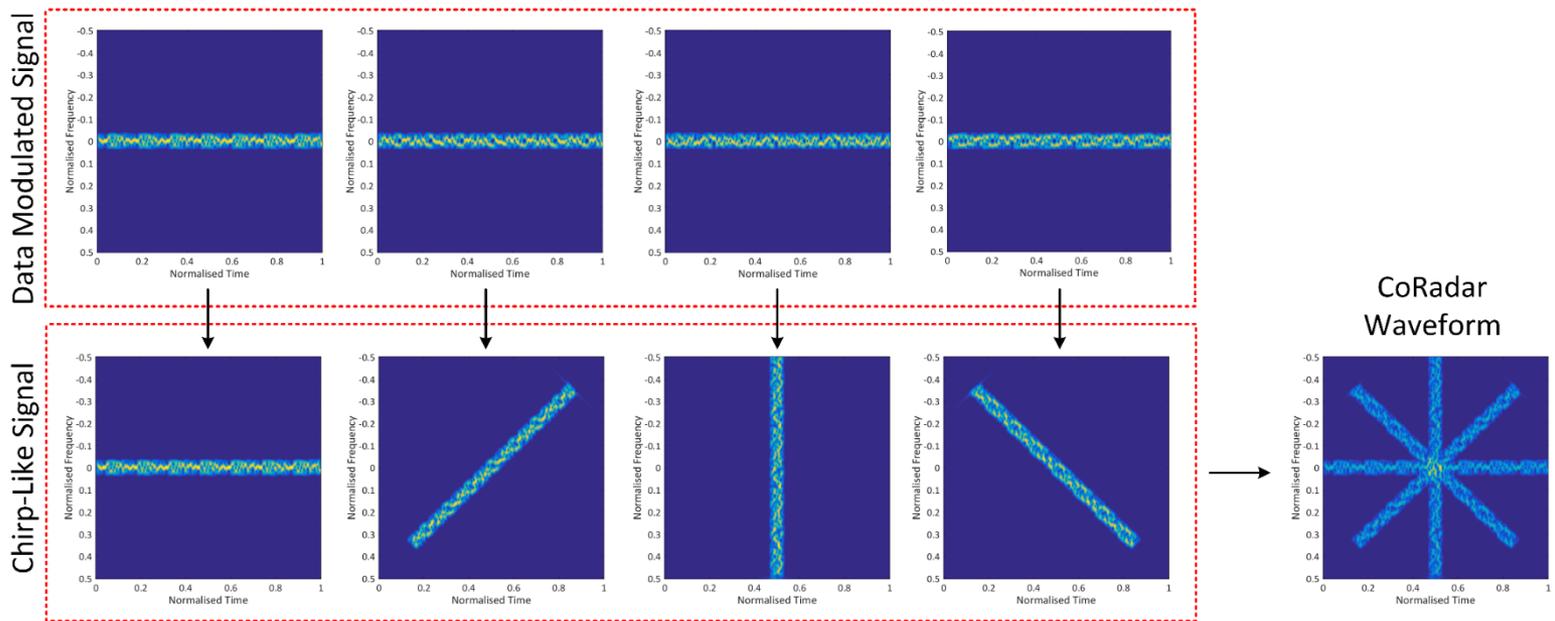


# Co-Radar – Waveform Design

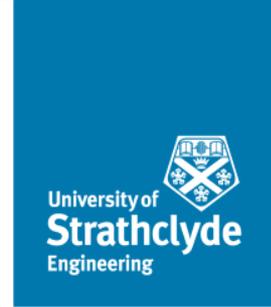
## Chirp Division Multiplexing

**Aim** Develop a novel radar waveform that embeds data while keeping the good properties of a LFM pulse.

**Idea** Different **chirp-like signals** that embed the information to transmit are generated and multiplexed (combined) to form the **Co-Radar pulse**.

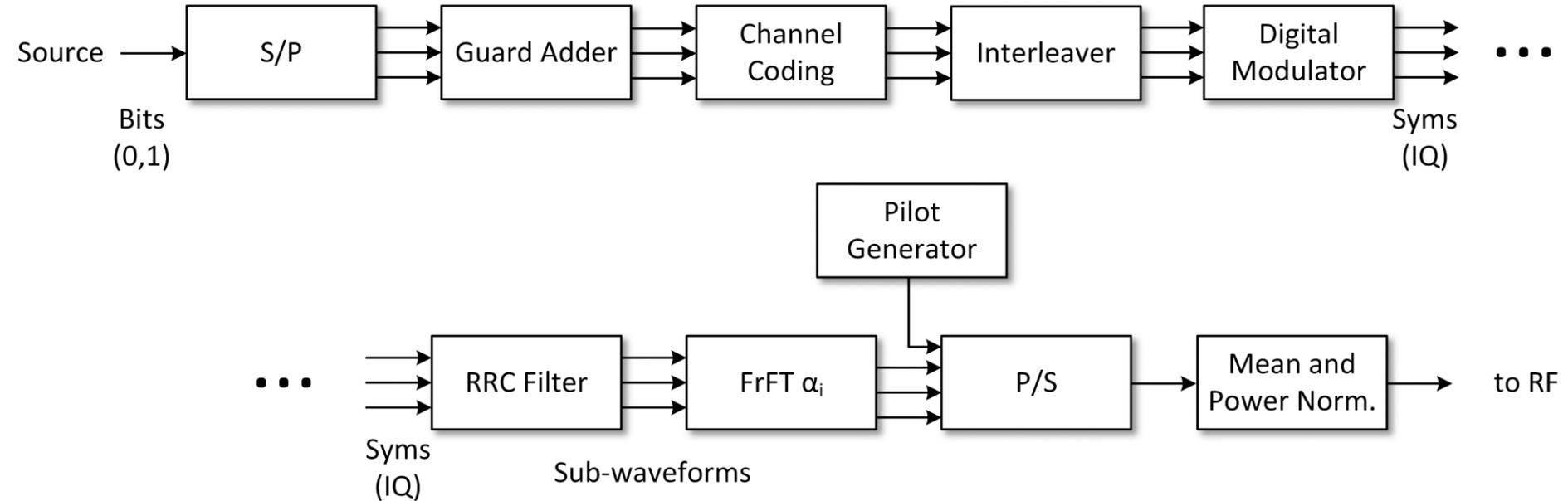


The mathematical tool that provides a chirp-like representation of a generic signal is the **Fractional Fourier Transform (FrFT)**, a generalisation of the well-known Fourier Transform.



# Co-Radar – Waveform Design

## Block Diagram

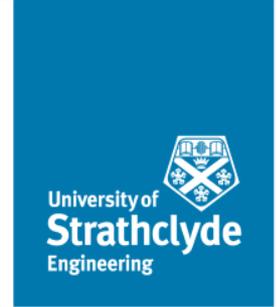


- A **repetition Error Correcting Code (ECC)** is used with a Barker code sequence;
- The **Interleaver** is used as Inter-Carrier Interference (ICI) mitigation technique;
- The **pilot waveform** is a bi-phase coded signal run by a Coarse/Acquisition (C/A) code.

# Co-Radar – Waveform Design

## Interleaver for ICI Mitigation

Sequence (*datawords*) to be transmitted on the  $i$ -th sub-carrier

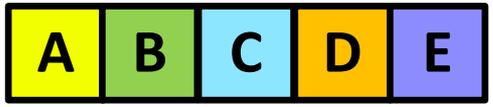




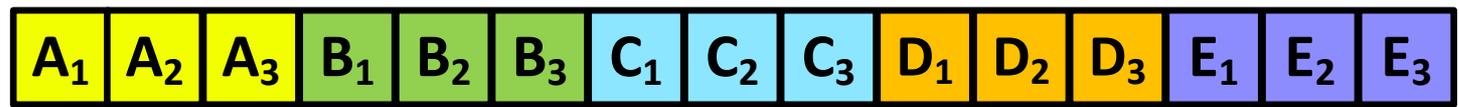
# Co-Radar – Waveform Design

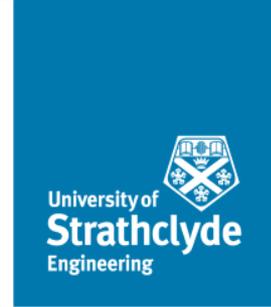
## Interleaver for ICI Mitigation

Sequence (*datawords*) to be transmitted on the *i*-th sub-carrier



Channel Coding – Barker Code  $L = 3$





# Co-Radar – Waveform Design

## Interleaver for ICI Mitigation

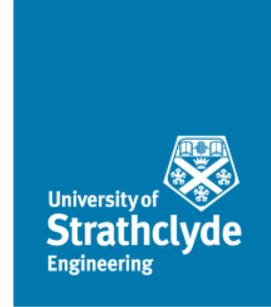
Sequence (*datawords*) to be transmitted on the *i*-th sub-carrier



Channel Coding – Barker Code  $L = 3$



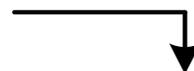
**ICI entirely affects *dataword C*.**



# Co-Radar – Waveform Design

## Interleaver for ICI Mitigation

Sequence (*datawords*) to be transmitted on the *i*-th sub-carrier

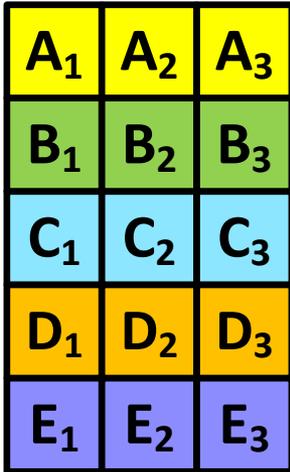


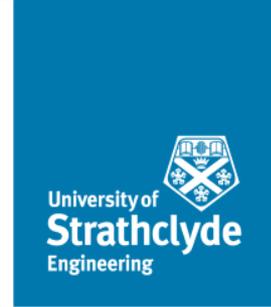
Channel Coding – Barker Code  $L = 3$



**ICI entirely affects *dataword C*.**

Input  
By Row

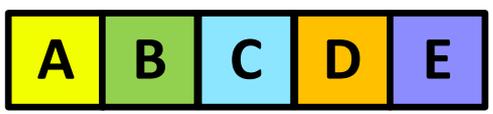




# Co-Radar – Waveform Design

## Interleaver for ICI Mitigation

Sequence (*datawords*) to be transmitted on the *i*-th sub-carrier

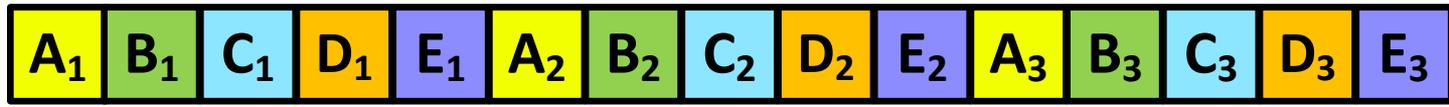
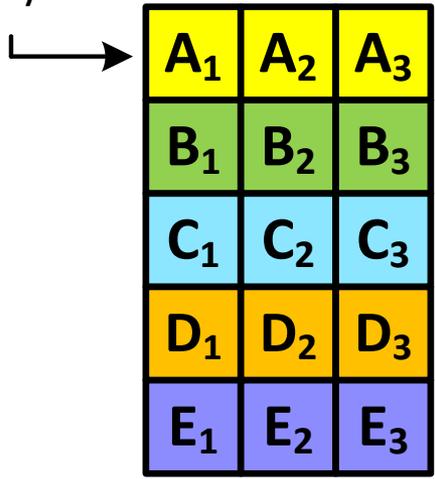


Channel Coding – Barker Code  $L = 3$

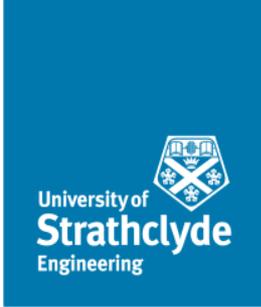


**ICI entirely affects *dataword C*.**

Input  
By Row



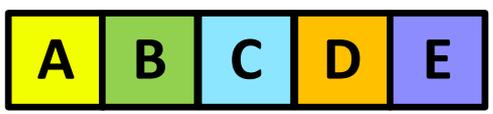
Output  
By Column



# Co-Radar – Waveform Design

## Interleaver for ICI Mitigation

Sequence (*datawords*) to be transmitted on the *i*-th sub-carrier

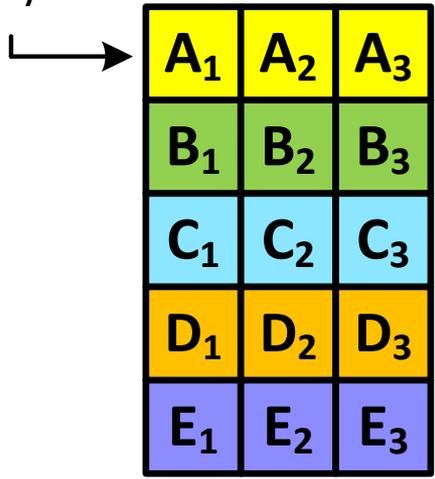


Channel Coding – Barker Code  $L = 3$



**ICI entirely affects *dataword C*.**

Input  
By Row



**ICI affects one bit of the *codeword* for each *dataword*.**

Since the employed repetition ECC can correct up to  $\lfloor L/2 \rfloor = 1$  error, the transmitted sequence can be correctly retrieved

Output  
By Column



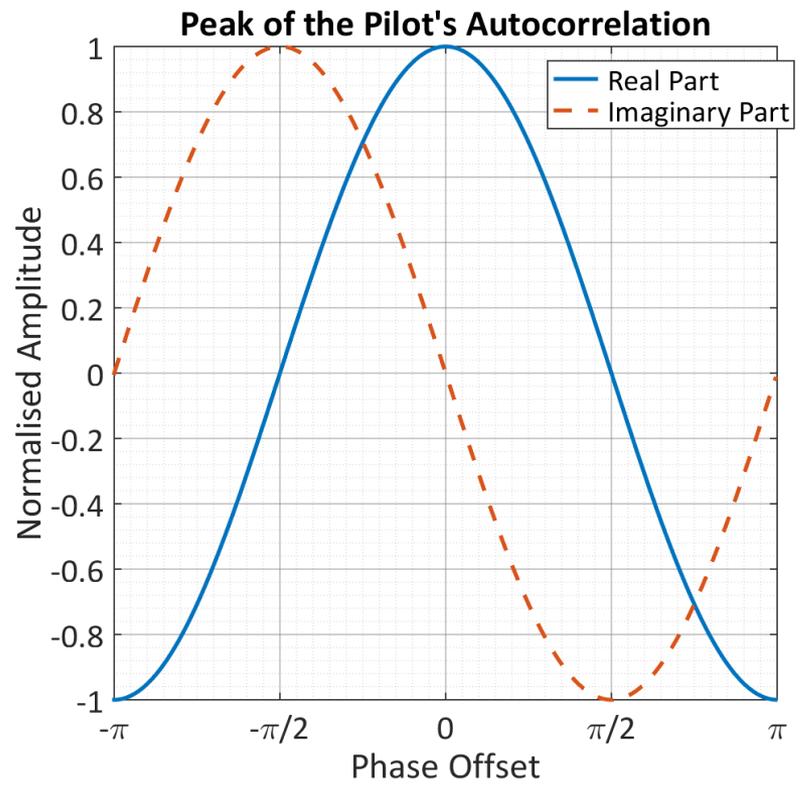
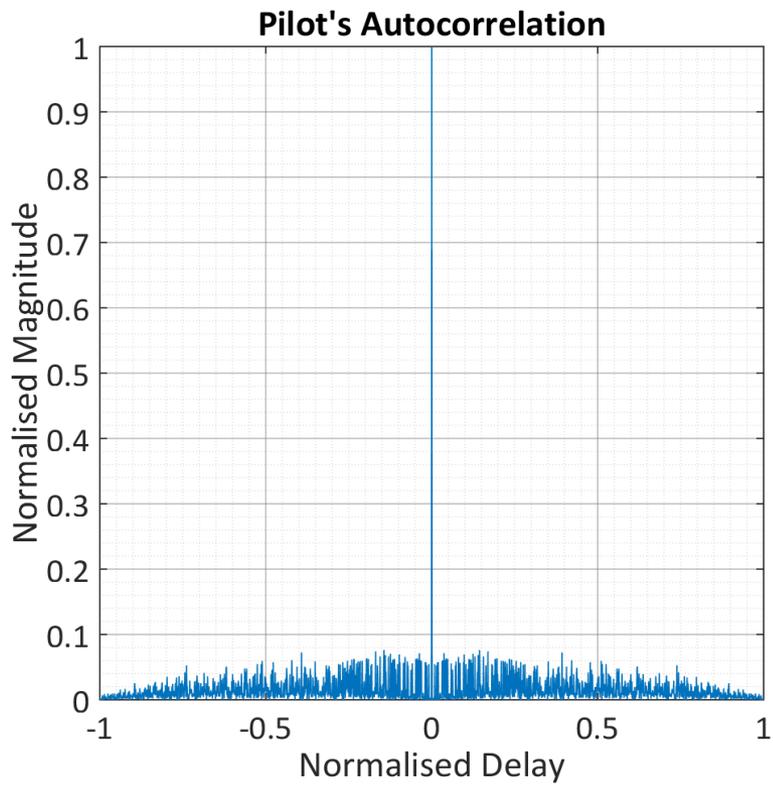
# Co-Radar – Waveform Design

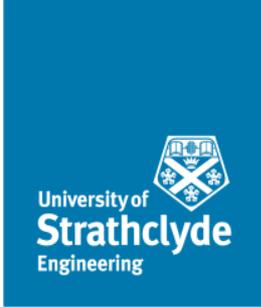
## Pilot Waveform

The **pilot waveform** is a bi-phase coded signal run by a Coarse/Acquisition (C/A) code:

$$p[n] = e^{j\pi(a[n]-\frac{1}{4})}$$

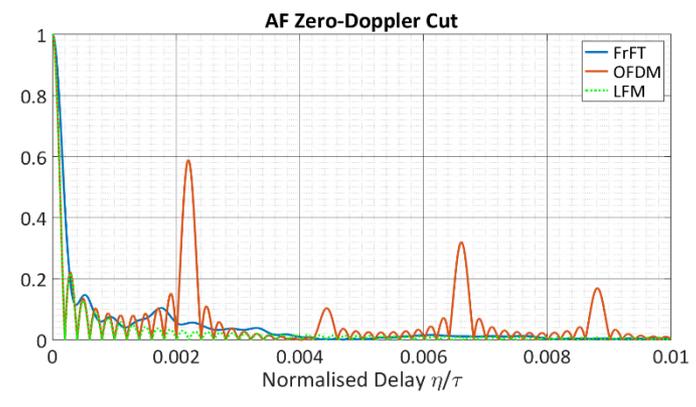
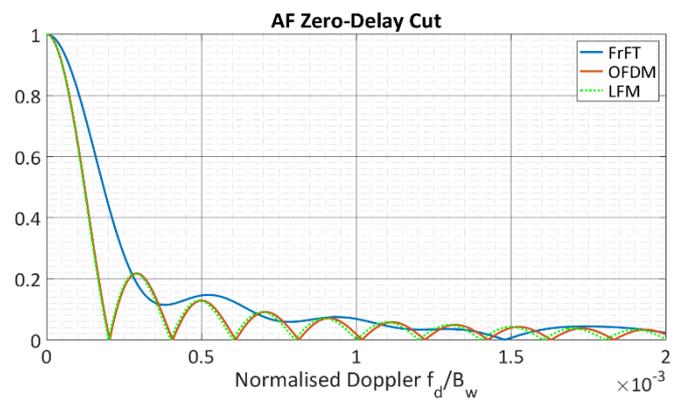
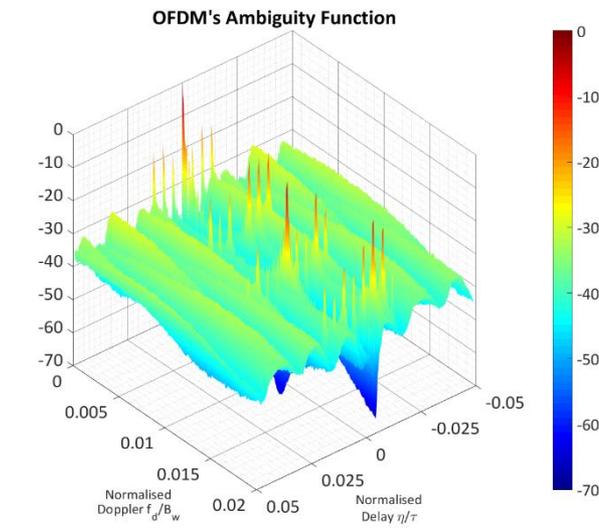
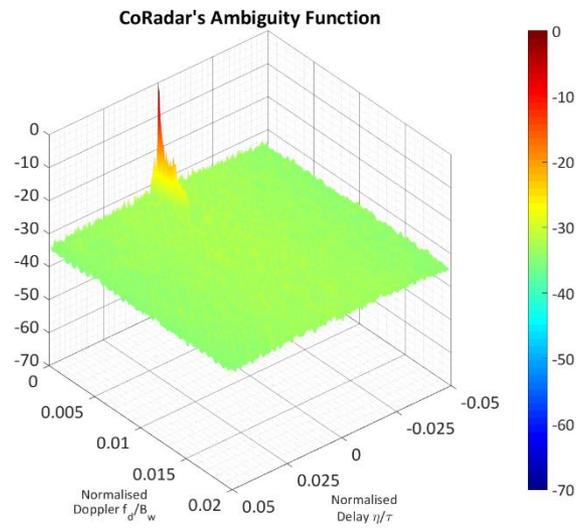
where  $a[n]$  is the selected C/A code.



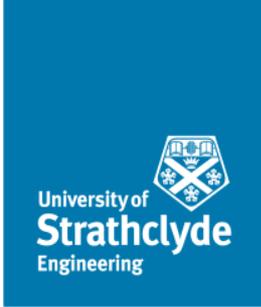


# Co-Radar – Comparison w/OFDM

Radar

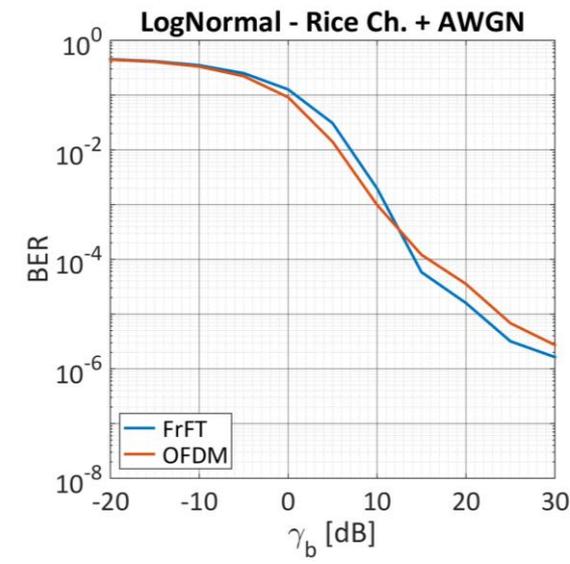
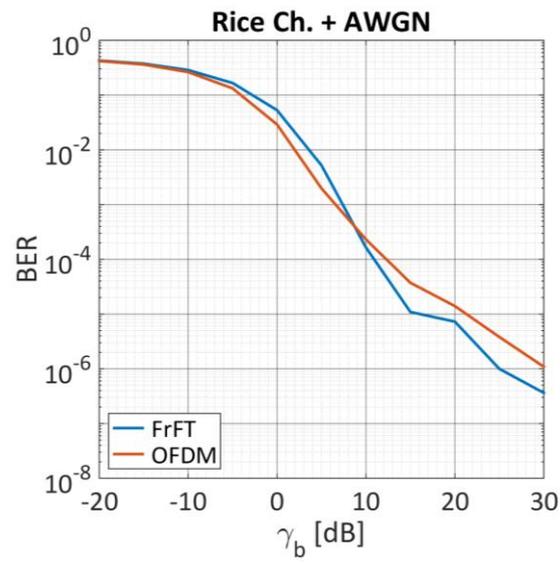
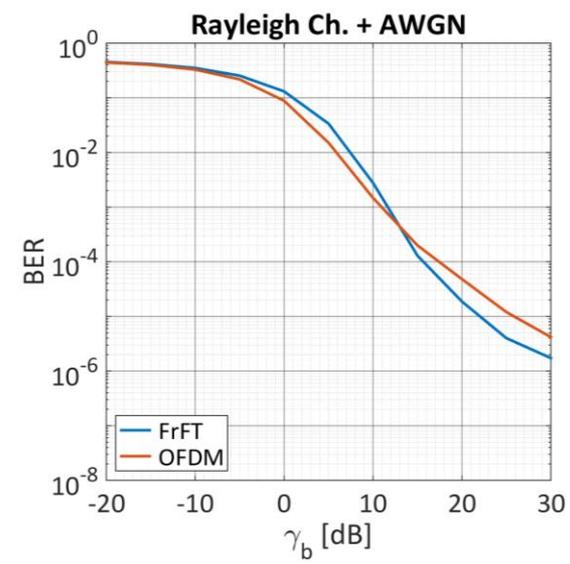
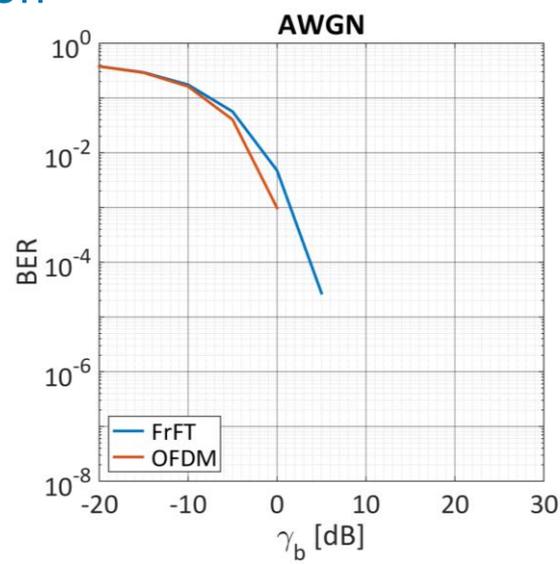


**Resolution is slightly traded with much better Side-lobe Levels compared to the OFDM.**



# Co-Radar – Comparison w/OFDM

## Communication



# Experimental Validation

## Equipment

The system has been implemented by means of a Software Defined Radio (SDR) device and validated in a controlled laboratory environment.

**SDR NI-USRP 2943r**



**Horn Antenna x3  
A-INFO LB-2678-15**



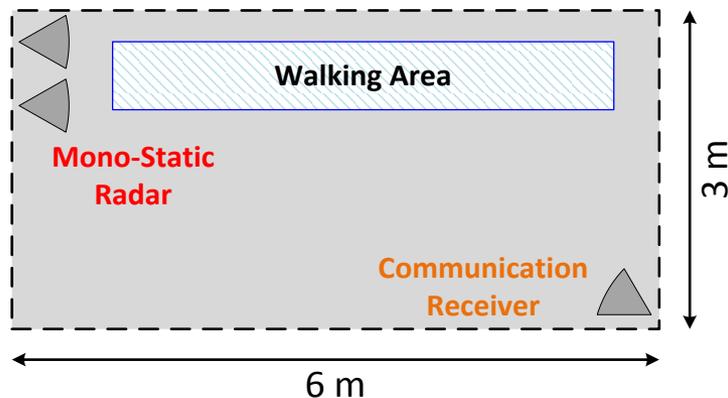
National Instruments (NI) Universal Software Radio Peripheral (USRP) 2943r:

- 2 receivers and 2 receivers/transmitters;
- Carrier frequency 1.2-6.6 GHz, max bandwidth 20 MHz;
- Equipped with a fully programmable Xilinx Kintex-7 FPGA;
- Easy for prototyping through LabVIEW.

# Experimental Validation

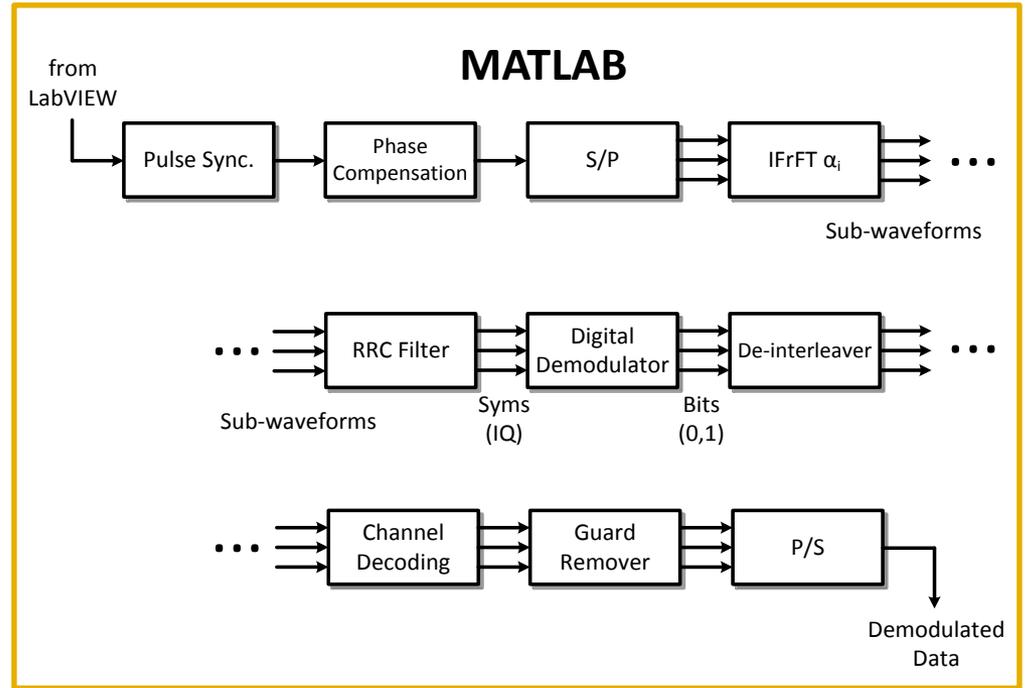
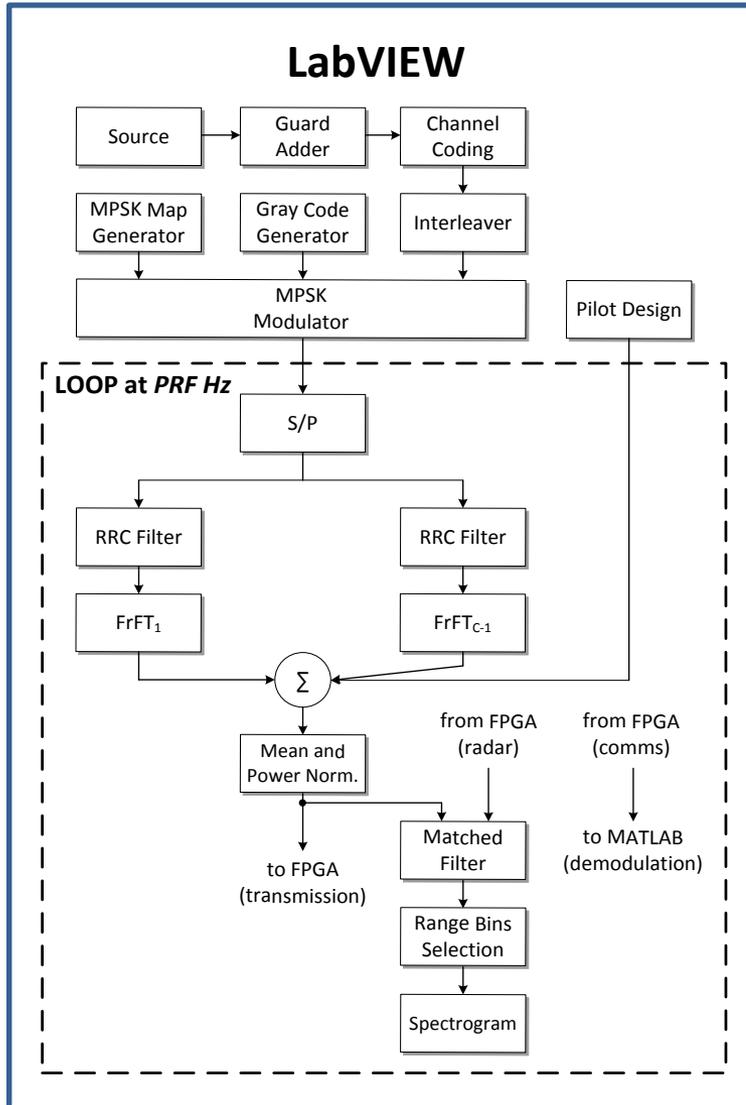
## Setup

- The system is composed by a **Mono-Static Radar** and a **Communication Receiver**;
- The **Mono-Static Radar**:
  - 1) generates the Co-Radar pulses which embed an image;
  - 2) listen to echoes and matched filters them;
- The **Communication Receiver** acquires the pulses and demodulates them.



# Experimental Validation

## Implementation



- **LabVIEW** deals with the generation of the Co-Radar waveforms, their transmission and the reception of both the radar and the communication signals.
- The latter, once acquired, are then transferred to a **MATLAB** session which extracts the embedded data.

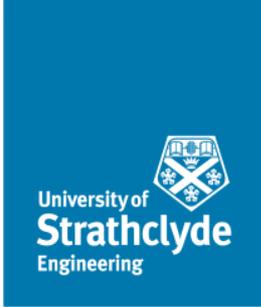
# Experimental Validation

Video



**Communicating Radar Technology Using Fractional Fourier Transform Division Multiplexing**

<https://www.youtube.com/watch?v=837krJcAUKQ>

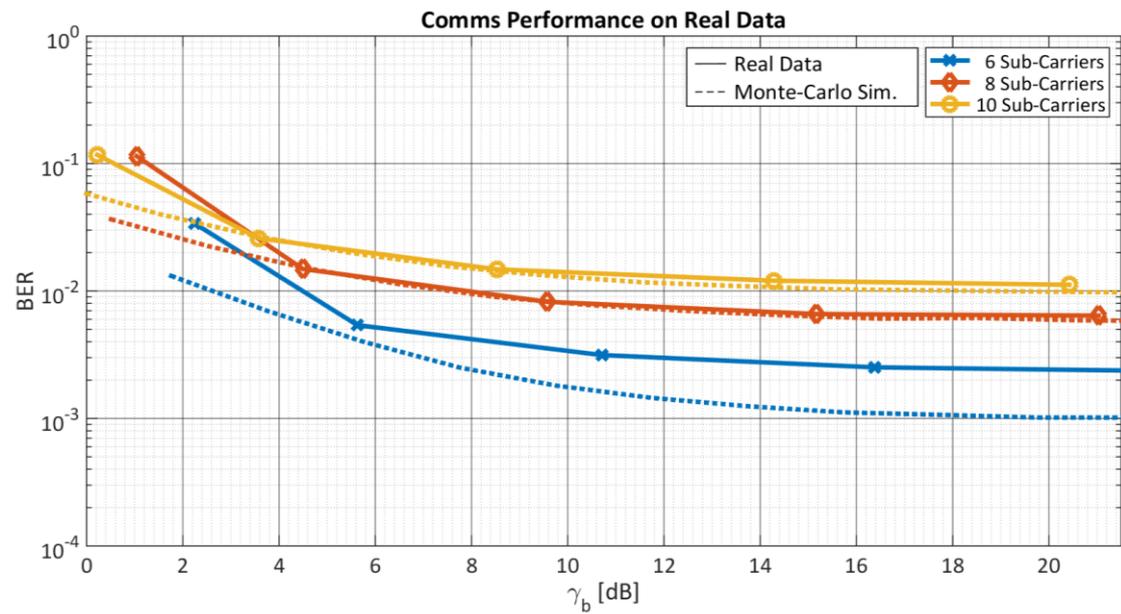
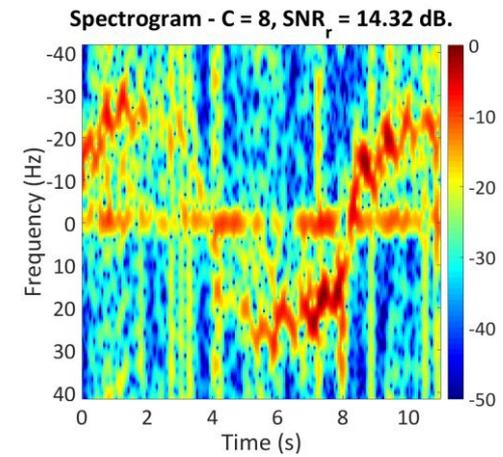
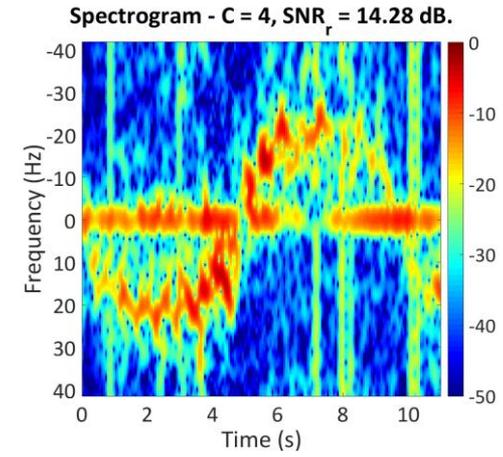


# Experimental Validation

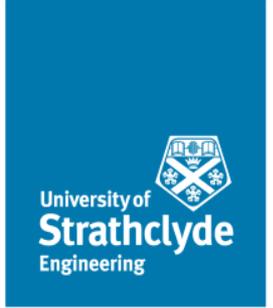
## Results

### System Configuration:

- Carrier frequency 3 GHz, bandwidth 1 MHz;
- Pulse length 378  $\mu$ s, PRF 83.33 Hz;
- 3 bits per sub-carrier, repetition ECC with Barker code  $L = 7$ ;
- Number of sub-carriers: 4, 6, 8, 10.



# Conclusions



- A novel joint Radar-Communication waveform design framework based on the Fractional Fourier Transform was presented.
- It allows to efficiently use the hardware, power and bandwidth resources already allocated for radar purposes to also send data to another cooperative system.
- The FrFT Co-Radar system was successfully implemented on a SDR device and its performance demonstrated in a controlled laboratory environment.
- Results show the capability of the proposed system of supporting simultaneously radar and communication tasks while sharing hardware, power and bandwidth resources.

Thank you!  
Any Question?



University of  
**Strathclyde**  
**Glasgow**