Interference Reduction Based on Hyperbolic Fractional Fourier Transform in Integrated Sensing and Communication

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The motivation:

- **Integrated sensing and communication (ISAC)**
  - The prominent application ⟹ toward 6G
    - Joint communication and sensing (JCAS)
    - Joint communication and radar (JCR)
    - Dual function radar communication (DFRC)

- Interference reduction ⟹ Common issue for telecommunication systems
  - Intended interference cancellation ⟹ security challenges of ISAC

- Fractional Fourier transform (FrFT) ⟹ Generalized form of Fourier transform ⟹ Chirp decomposition
  - FrFT-based Multicarrier systems
  - FrFT- based Radar signal processing
    - The main weakness ⟹ Only limited real and optimized orders of transform

Hyperbolic Fractional Fourier Transform (HFrFT)

- Continuous HFrFT:

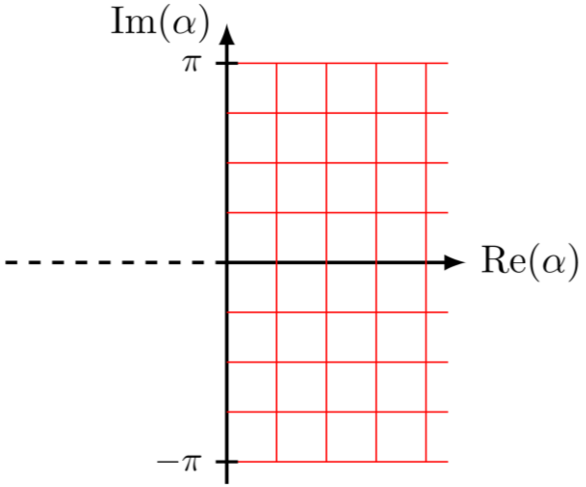
Transform kernel

$$\mathcal{F}_{\alpha}^{\mathrm{h}}\left\{x(\tilde{t})\right\}(\tilde{v}) = \int_{-\infty}^{\infty} x(\tilde{t}) \cdot \underbrace{A \cdot \mathrm{e}^{-\pi(\tilde{t}^2+\tilde{v}^2)\coth(\alpha)}}_{\text{Gaussian shape}} \cdot \underbrace{\mathrm{e}^{2\pi\tilde{t}\tilde{v}\,\mathrm{csch}(\alpha)}}_{\text{wavelet shape}}\, \mathrm{d}\tilde{t}$$

$x(\tilde{t})$: The input signal

$\tilde{t} := {}^{t}/_{s}$, $\tilde{v} := {}^{v}/_{Hz}$

$$A = \frac{\mathrm{e}^{-\jmath\left(\frac{\pi}{4}-\frac{|\alpha|}{2}\right)}}{\sqrt{2\pi\jmath\sinh(\alpha)}}$$



$\alpha \in \mathbb{C}$ $\begin{cases} \Re(\alpha) > 0 \\ 0 < |\Im(\alpha)| < \pi \end{cases}$

- For $\alpha = j\,\frac{\pi}{2}$ HFrFT ➡ Fourier transform (FT)

Signal model

$$r(t) = \sum_{l=0}^{L-1} h_l(t) y(t - lT)$$

$$+ \sum_{n=-\infty}^{\infty} \left(\frac{\tilde{A}\tau}{T_o}\right) \mathrm{sinc}\left(\frac{n\tau}{T_o}\right) . e^{j2n\pi \frac{t}{T_o}} + \omega(t)$$

Fourier series expansion of the Pulse train interference

AWGN noise

$$y(t) = \sum_{m=0}^{N-1} \hat{X}_\alpha^{\mathrm{h}}[m] g(t - mT), \qquad 0 \le t < T_s$$

- $\hat{X}_\alpha^h$: Transmitted symbol with subcarrier m
- g : baseband pulse shaping function
- T_s: Symbol interval
- h_l: lth path fading channel response
- $\tilde{A}$: Pulse amplitude
- τ: pulse width
- T_o: pulse period
- $\omega(t)$: AWGN noise

The received signal plus pulse train interference and AWGN noise

Simulation result

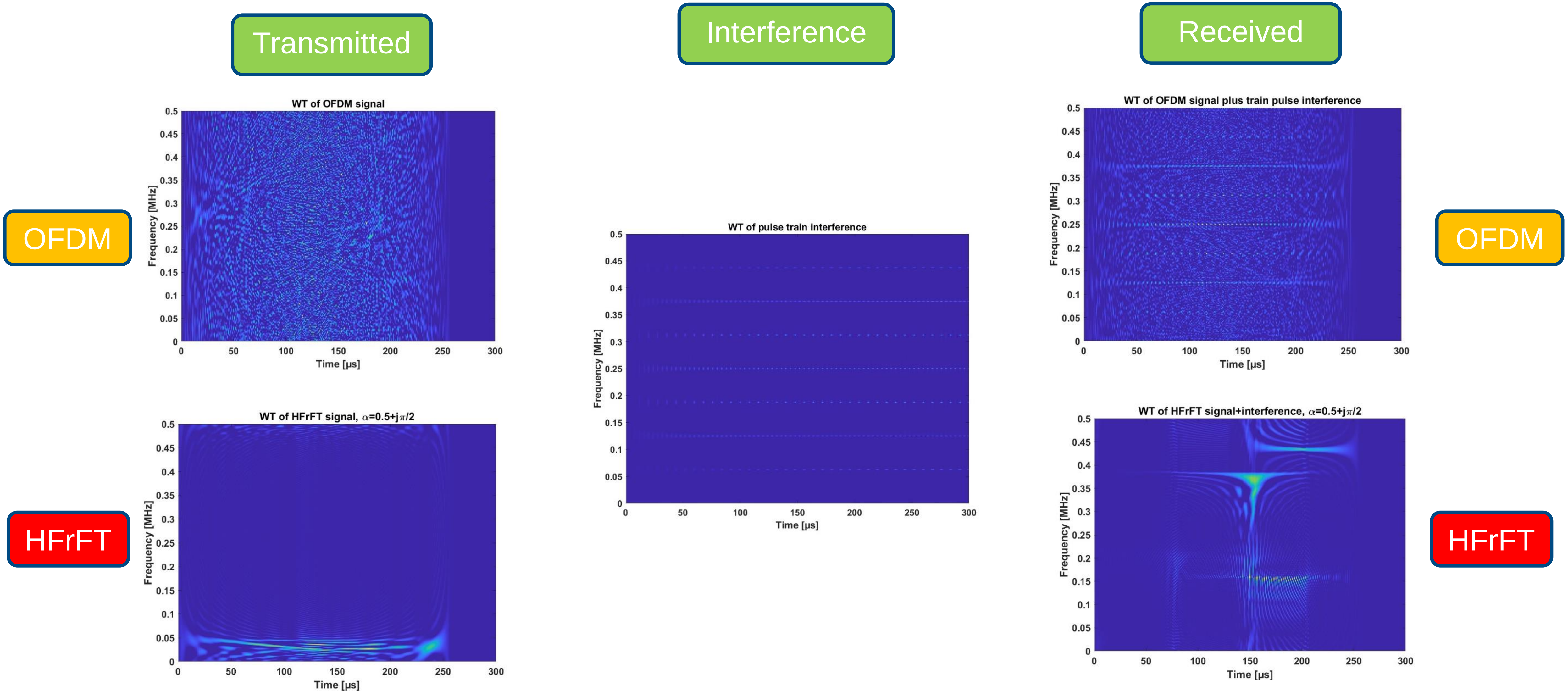


Fig. 1. Comparison between WT analysis of OFDM and HFrFT with the selected transform orders $\alpha = 0.5 + j\frac{\pi}{2}$ interfered with a pulse train interference

Simulation result

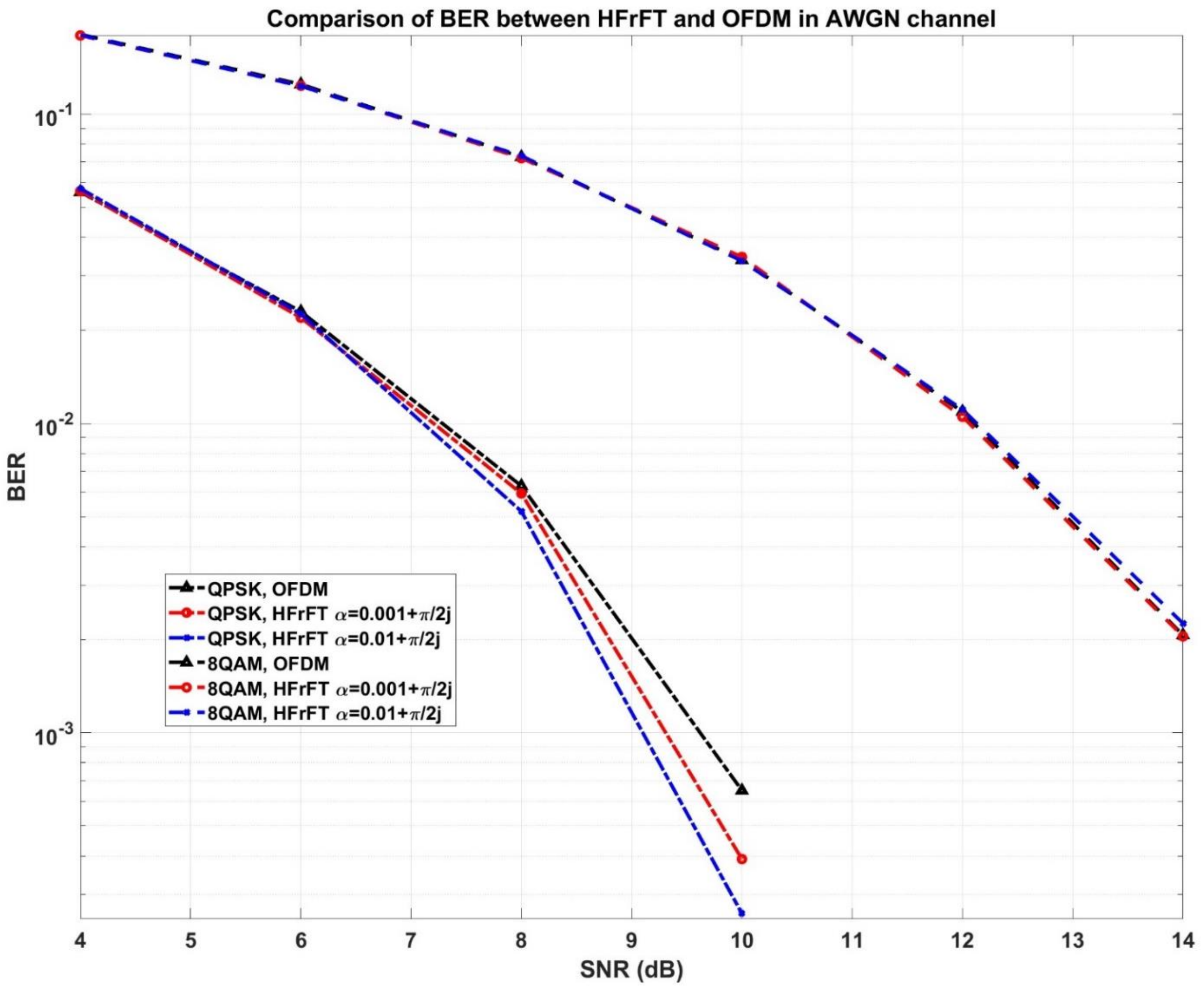


Fig. 2. Comparison of BER versus SNR for HFrFT and OFDM system in the AWGN channel for QPSK and QAM modulation schemes

Conclusion

- HFrFT results in a better BER performance especially in the QPSK scheme compared to ordinary OFDM
- Reducing the intended interference in HFrFT for the selected transform orders is easier compared to the ordinary OFDM
- Using the HFrFT technique in ISAC applications can produce better performance in both communication and sensing and introduce HFrFT as a suitable nomination in ISAC applications
- Open issues: Optimization of the transform order, the theoretical BER calculation for modulation schemes and different channels, and the throughput and complexity calculation for multi-user, multi-target, and MIMO scenarios

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Thank You

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