Division of Advanced Science and Biotechnology,
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Recent progress on Photonic Time-Frequency Signal Processing

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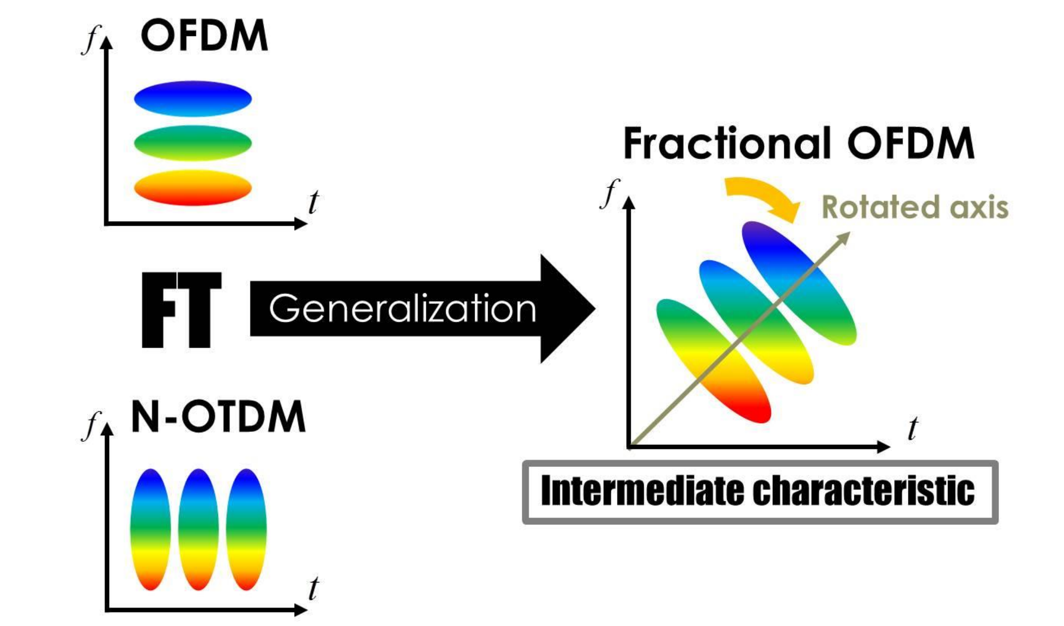
Our research and education cover the multidisciplinary fields of ultrafast photonics, signal processing and various measurements. We are exploring optical system solutions based on novel concepts for a wide range of signal processing applications including next-generation photonic networks, remote sensing, astronomy and so on. Here, multi-dimensional property of light in time and space domains suggests the latent potential of ultra-fast and massive parallel optical signal processing.

In photonic networks, transmission capacity demand will reach seventy-six Exabyte per month in two thousand fifteen and one-hundred-thirty-two Exabyte in two thousand eighteen. To satisfy the increasing capacity demand, optical fiber simultaneously transmits huge number of sub-carriers, for example based on orthogonal frequency division multiplexing (OFDM) and Nyquist-optical time division multiplexing (N-OTDM) [1,2]. However, unfortunately, we have either-or options. This will restrict flexibility of a future elastic network based on diversity of distance, components, and modulation formats. To exploit new flexibility of multiplexing schemes, it would be ideal to make balance between OFDM and N-OTDM because they have pros and cons. Therefore, we have explored the latent potential in intermediate domain between time and frequency, that is Fractional OFDM. [3-8]. Fractional Fourier transform (FrFT) allows us to introduce the largest degree of flexibility in elastic networks[9], moving from time to frequency multiplexing and vice versa.

These works are partially supported by several fundings, e.g. STARBOARD project of MIC Strategic Harmonized International R&D Promotion Programme (SHIP).



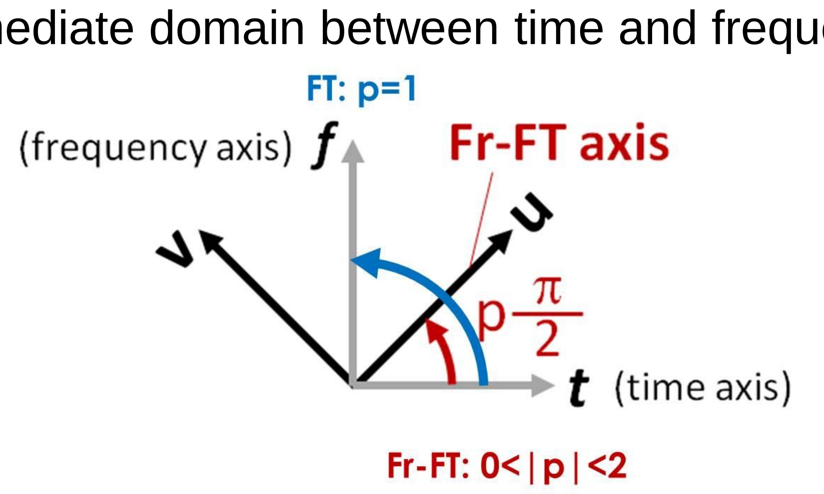
Exploitation of New flexibility in Time-Frequency signal processing

[1] D. Hillerkuss, et al., Nat. Photon., vol. 5, pp. 364–371 (2011).
[2] M. Nakazawa et al., Opt. Express, vol. 20, pp.1129-1140 (2012).
[3] G. Cincotti, in Proc. SPIE 8284, 828409(2012).
[4] G. Cincotti, et al., in PS.2014, PT1B.3 (2014).
[5] T. Murakawa, et al., in OFC 2015, paper W3C.1 (2015).
[6] G. Cincotti et al. , in OFC 2015, paper W3C.5 (2015).
[7] T. Konishi, et.al., Optical Fiber Technology, 26, pp.94–99, (2015) .
[8] M. Jinno, et al., IEEE Commun Mag., vol. 47, no. 11, pp. 66-73 (2009).

TOPIC 1

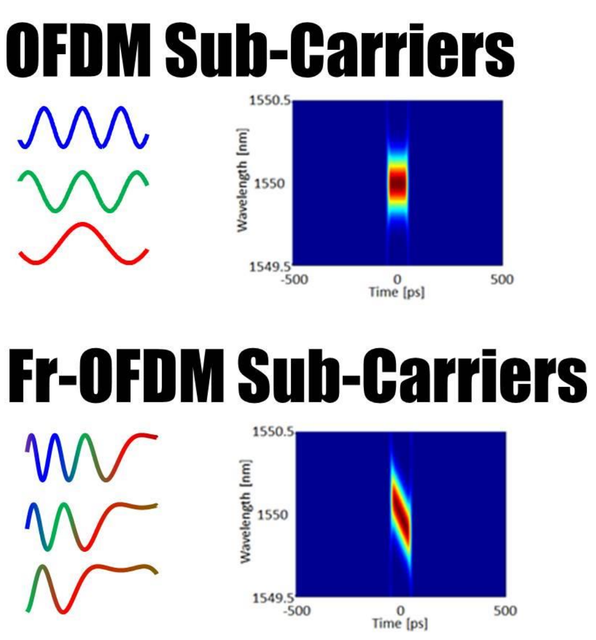
Principle of Fr-Fourier Transform

The FrFT is a generalization of the FT, that deals with the intermediate domain between time and frequency axes. The p is fractional parameter which means rotation degree on time-frequency map. For example, the general FT corresponds to the case for p=1. As shown in the right figure, the FT can be seen as the projection of a given temporal signal on the frequency axis. The FrFT can be interpreted as the projection of the temporal signal on an intermediate axis that forms an angle $p\pi/2$ with $0<|p|<2$.



Fractional Fourier Transform

TOPIC 2



OFDM and Fr-OFDM Sub Carriers

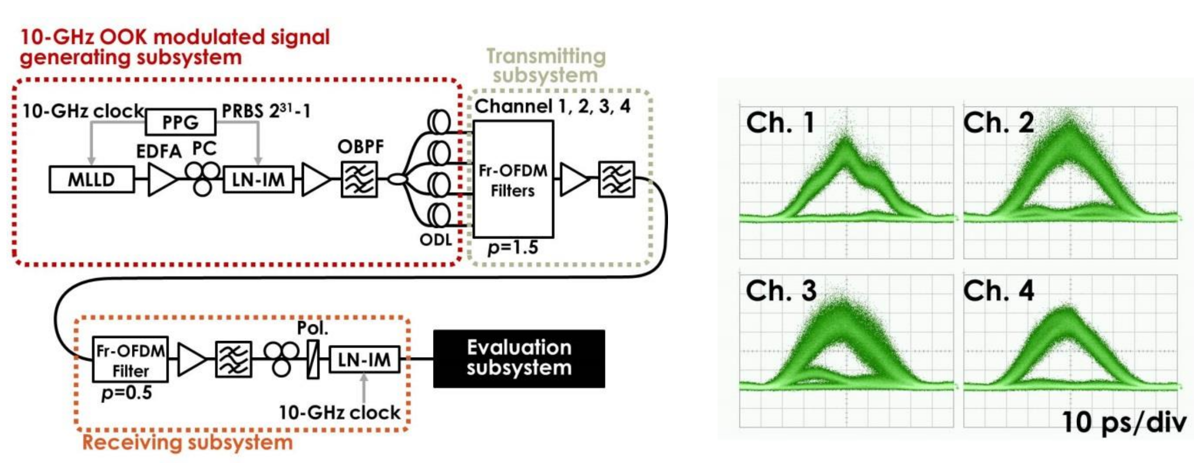
Proposed Fr-OFDM sub-carriers[3,4]

In a conventional OFDM, subcarriers are expressed by Fourier transform, as shown in the upper figure. On the other hand, subcarriers of fractional OFDM have orthogonal relations on rotated axis. These subcarriers are expressed by fractional Fourier transform as shown in the bottom figure. If p=1, subcarriers are equal to conventional OFDM subcarriers. As you can see, Fr-OFDM subcarrier contains a frequency dependent chirp factor which is derived from their Quadratic Phase Modulation (QPM) factors and can inherently reduce PAPR in transmission.

TOPIC 3

Experimental demonstration for Fr-OFDM transmitter and receiver[5-7]

We have experimentally demonstrated a hybrid OFDM/N-OTDM using an time/frequency grid based on Fractional-OFDM. The left hand is the experimental setup. It consists of a transmitter with p=1.5 and a receiver with p=0.5. The right hand shows a series of eye diagrams of received signals for 4 sub-carriers. We observed clear eye opening of all the received signals.



10-GHz OOK transmission based on Fr-OFDM