

All-Quantum Signal Processing in Quantum Communication and Computation



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31.05.2023

College Acknowledgement

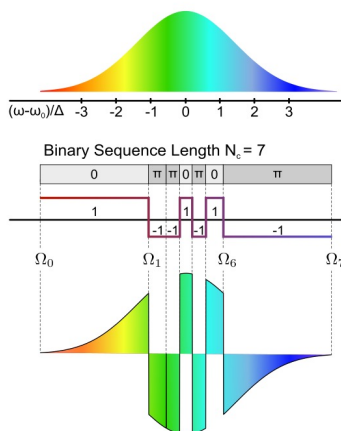


فروغ السادات طباطبایا
دانشکده مهندسی برق و کامپیوتر
دانشگاه صنعتی اصفهان



دنیا رضایی شاد
دانشجو دکتری
Q. PPM QKD

All-Quantum Signal Processing



جواد صالحی
دانشکده مهندسی برق و پژوهشکده همگرا



علی آقائی صانم
دانشجو دکتری
Q. Radar

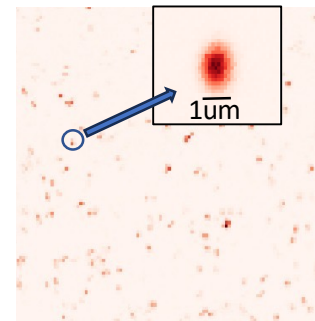


مرضیه بطحانی
پسا دکتری
Q. WDM



امیرمحمد دستغیب
دانشجو دکتری
Q. CDMA And Q. Lab

Single Photon Source Experiments



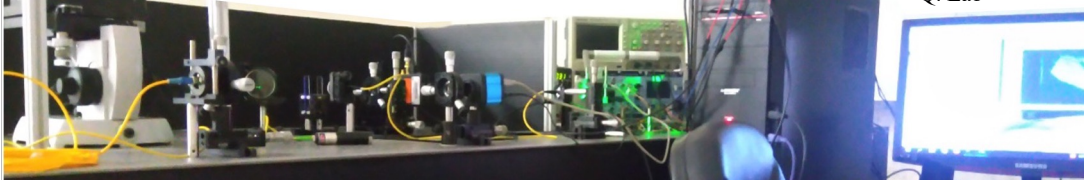
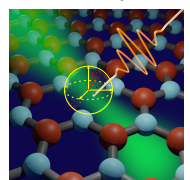
علی اسفندیار
دانشکده فیزیک و پژوهشکده همگرا



ابوالفضل ابراهیمی
کارشناسی ارشد
Q. Lab



مرتضی جعفری
پسا دکتری
Q. Lab

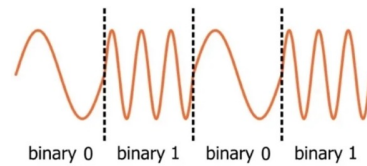


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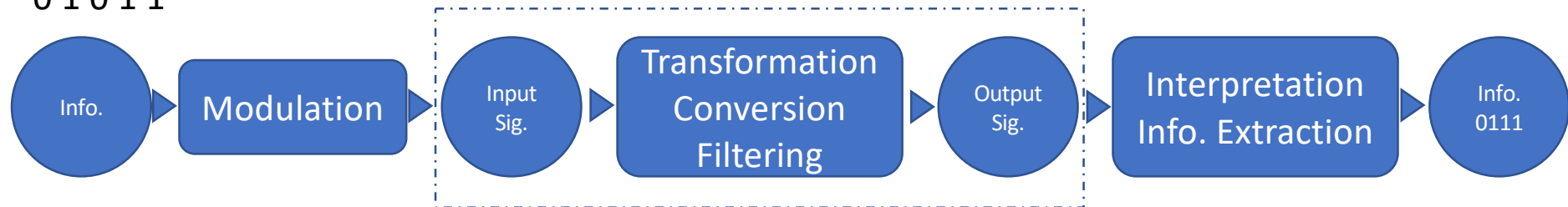
Signals Processing in Engineering



0 1 0 1 1

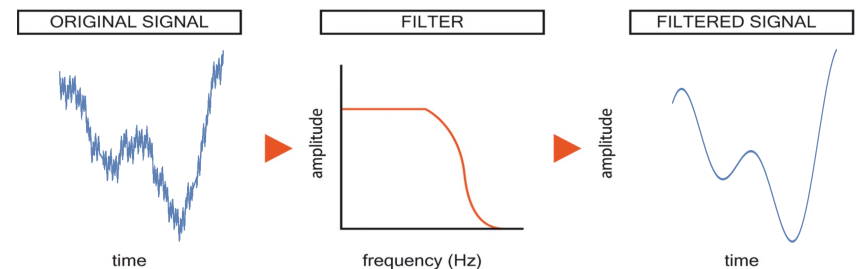


FSK Signal



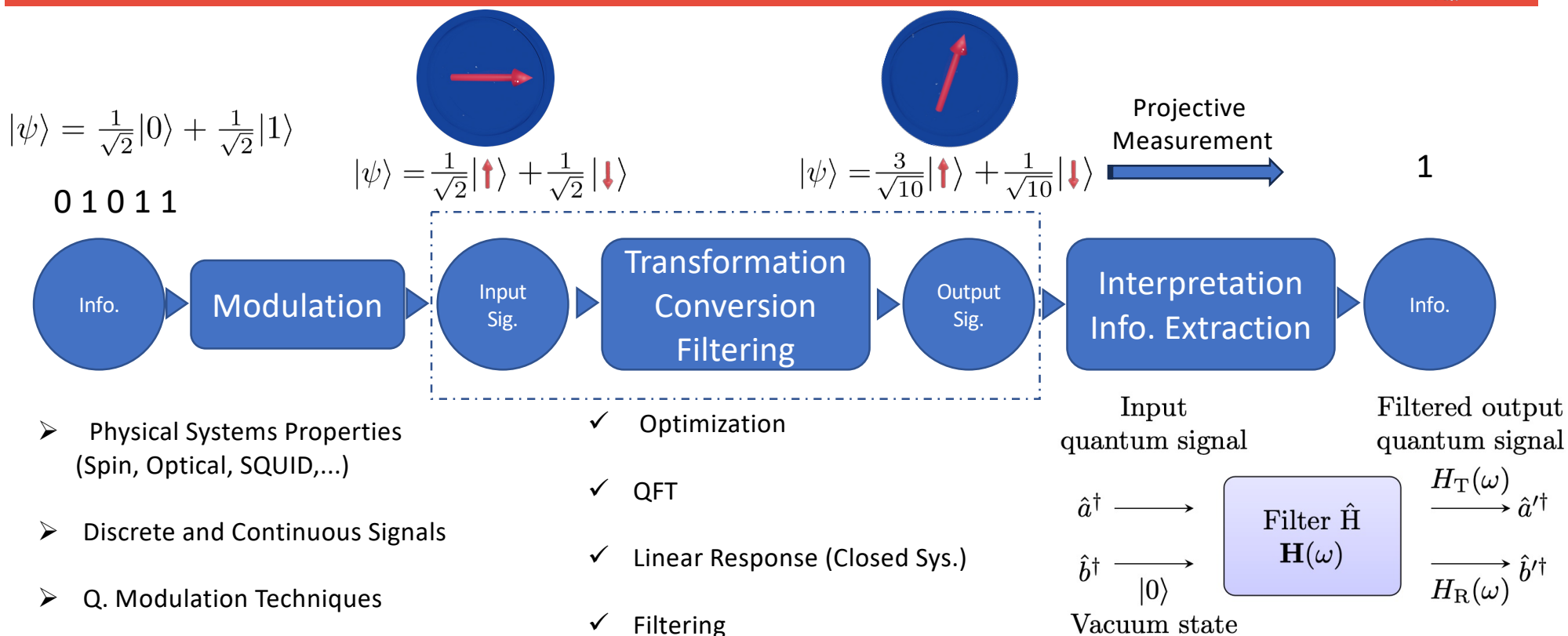
- Physical Systems Properties (Mechanical, Electrical, Optical,...)
- Digital and Analog Signals
- Modulation Techniques

- ✓ Optimization
- ✓ Fourier Transform
- ✓ Linear Response
- ✓ Filtering



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All-Quantum (Optical, ...) Signals Processing



Optics: Single Photon Quantum Signal

$$|e^{-}\rangle = \sum_{s=\uparrow,\downarrow} \int d^3p \tilde{\psi}_s(p_z, p_x, p_y) |p_z, p_x, p_y, s\rangle$$

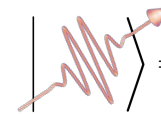
$$= \sum_{s=\uparrow,\downarrow} \int dE \iint dp_x dp_y \tilde{\psi}_s(E, p_x, p_y) |E, p_x, p_y, s\rangle$$

$$= \sum_{s=\uparrow,\downarrow} \int dE \iint dx dy \psi_s(E, x, y) |E, x, y, s\rangle$$

$$= \sum_{s=\uparrow,\downarrow} \int dt \iint dx dy \bar{\psi}_s(t, x, y) |t, x, y, s\rangle$$

$$|p_x\rangle = \frac{1}{\sqrt{2\pi\hbar}} \int dx e^{ip_x x} |x\rangle$$

$$|E\rangle = \frac{1}{\sqrt{2\pi\hbar}} \int dt e^{-iEt} |t\rangle$$



$$|\text{photon}\rangle = \sum_{\sigma=h,v} \int d^3k \tilde{\psi}_\sigma(k_z, k_x, k_y) |k_z, k_x, k_y, \sigma\rangle$$

$$= \sum_{\sigma=h,v} \int d\omega \iint dk_x dk_y \tilde{\psi}_\sigma(\omega, k_x, k_y) |\omega, k_x, k_y, \sigma\rangle$$

$$= \sum_{\sigma=h,v} \int d\omega \iint dx dy \psi_\sigma(\omega, x, y) |\omega, x, y, \sigma\rangle$$

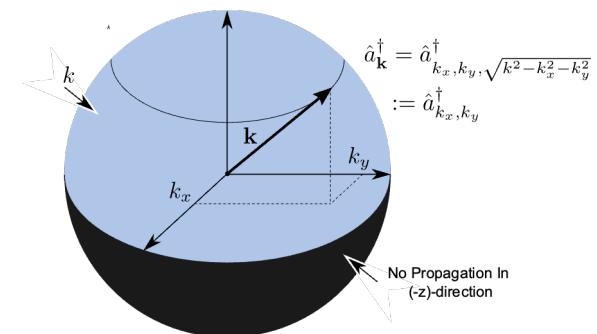
$$= \sum_{\sigma=h,v} \int dt \iint dx dy \bar{\psi}_\sigma(t, x, y) |t, x, y, \sigma\rangle$$

➤ Polarization. $\text{Dim}[H]=2$

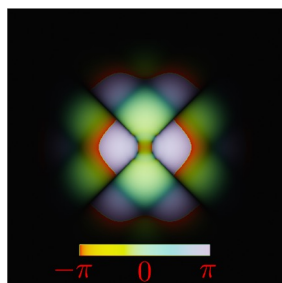
➤ Time/Frequency

➤ Wavefront/ 2D Wavevector:

$$\text{Dim}[H] \propto \frac{A}{\lambda^2} = \frac{(1\text{cm})^2}{(500\text{nm})^2} = 4 \times 10^8$$



Quantum Fourier Optics

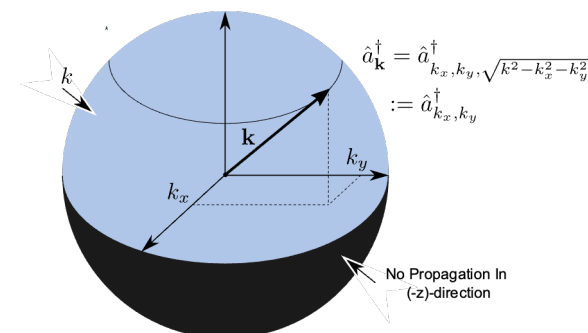


$\psi(x, y)$

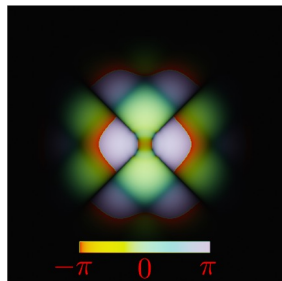
- Polarization
- Time/Frequency
- Wavefront/ 2D Wavevector:

$$\text{Dim}[H] \propto \frac{A}{\lambda^2} = \frac{(1\text{cm})^2}{(500\text{nm})^2} = 4 \times 10^8$$

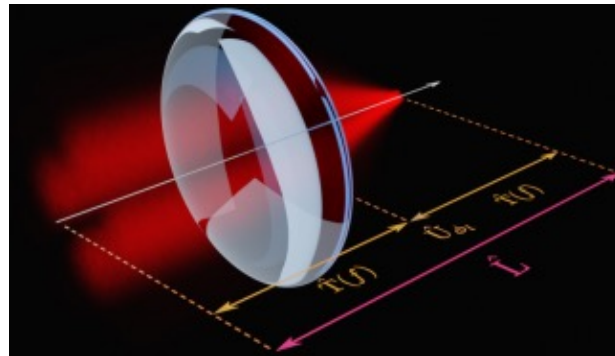
$$\begin{aligned} | \text{wave} \rangle &= \sum_{\sigma=h,v} \int d^3k \tilde{\psi}_{\sigma}(k_z, k_x, k_y) |k_z, k_x, k_y, \sigma\rangle \\ &= \sum_{\sigma=h,v} \int d\omega \iint dk_x dk_y \tilde{\psi}_{\sigma}(\omega, k_x, k_y) | \omega, k_x, k_y, \sigma \rangle \\ &= \sum_{\sigma=h,v} \int d\omega \iint dx dy \psi_{\sigma}(\omega, x, y) | \omega, x, y, \sigma \rangle \\ &= \sum_{\sigma=h,v} \int dt \iint dx dy \bar{\psi}_{\sigma}(t, x, y) | t, x, y, \sigma \rangle \end{aligned}$$



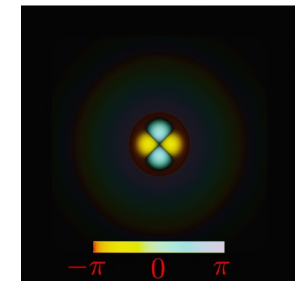
Quantum Fourier Optics



$$\psi(x, y)$$



$$|\psi_{\text{out}}\rangle = e^{\frac{-iH_L t}{\hbar}} |\psi\rangle$$

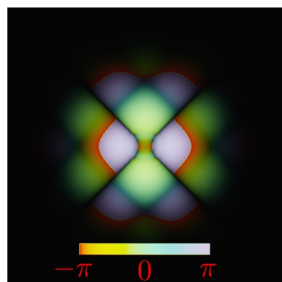


$$\psi_{\text{out}}(x, y) = FT[\psi(x, y)]$$

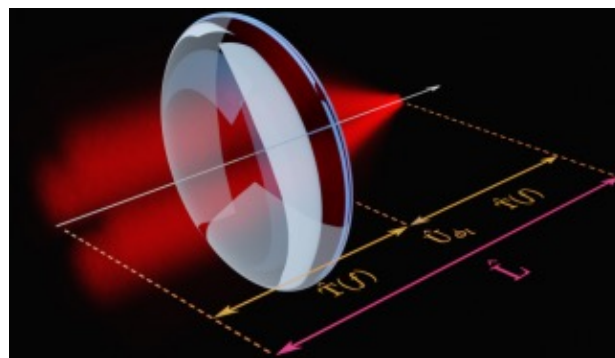
$$\psi_{\text{desir}}(x, y) =$$

$$D[\dots FT[D[FT[\psi(x, y)]]] \dots]$$

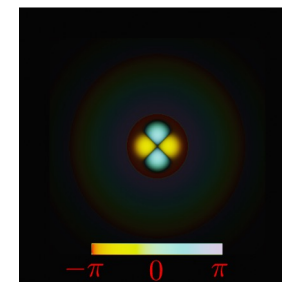
Quantum Fourier Optics



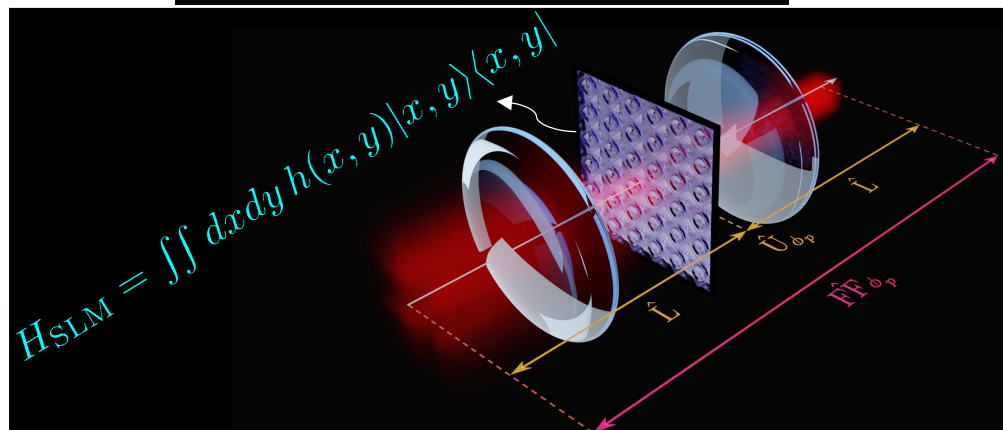
$\psi(x, y)$



$$|\psi_{\text{out}}\rangle = e^{\frac{-iH_L t}{\hbar}} |\psi\rangle$$



$$\psi_{\text{out}}(x, y) = FT[\psi(x, y)]$$



$$\psi_{\text{desir}}(x, y) =$$

$$D[\dots FT[D[FT[\psi(x, y)]]] \dots]$$

Quantum Computation via Quantum Fourier Optics

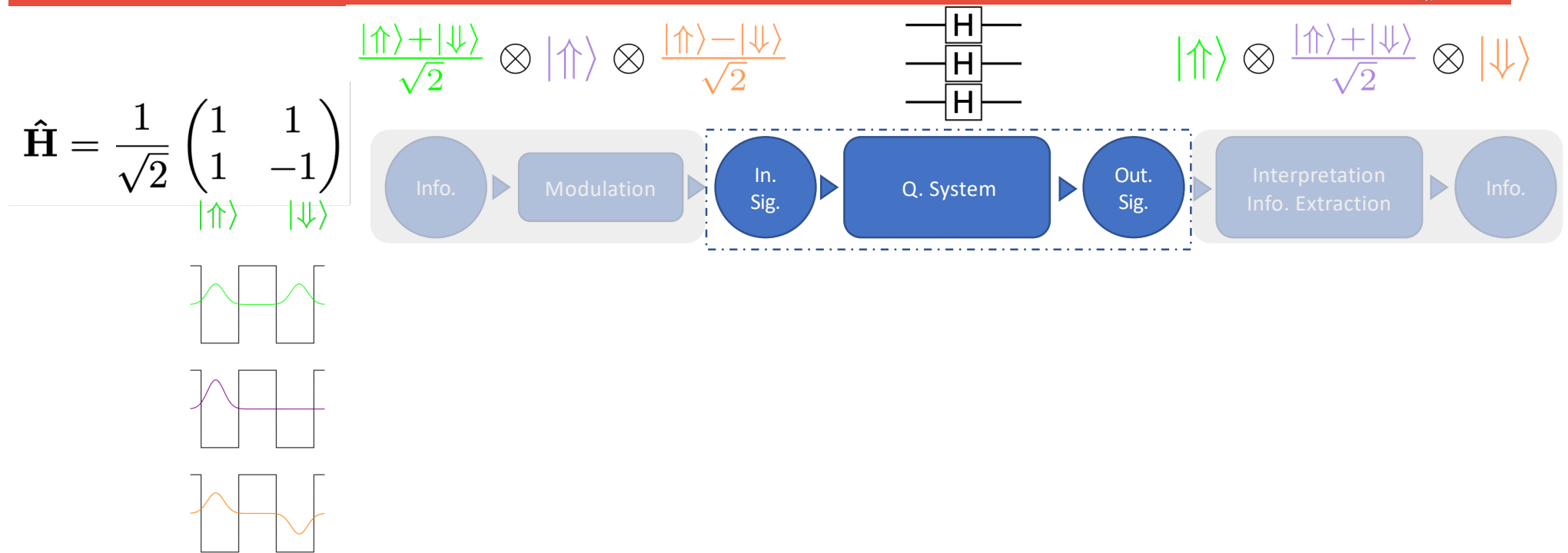


$$\hat{H} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

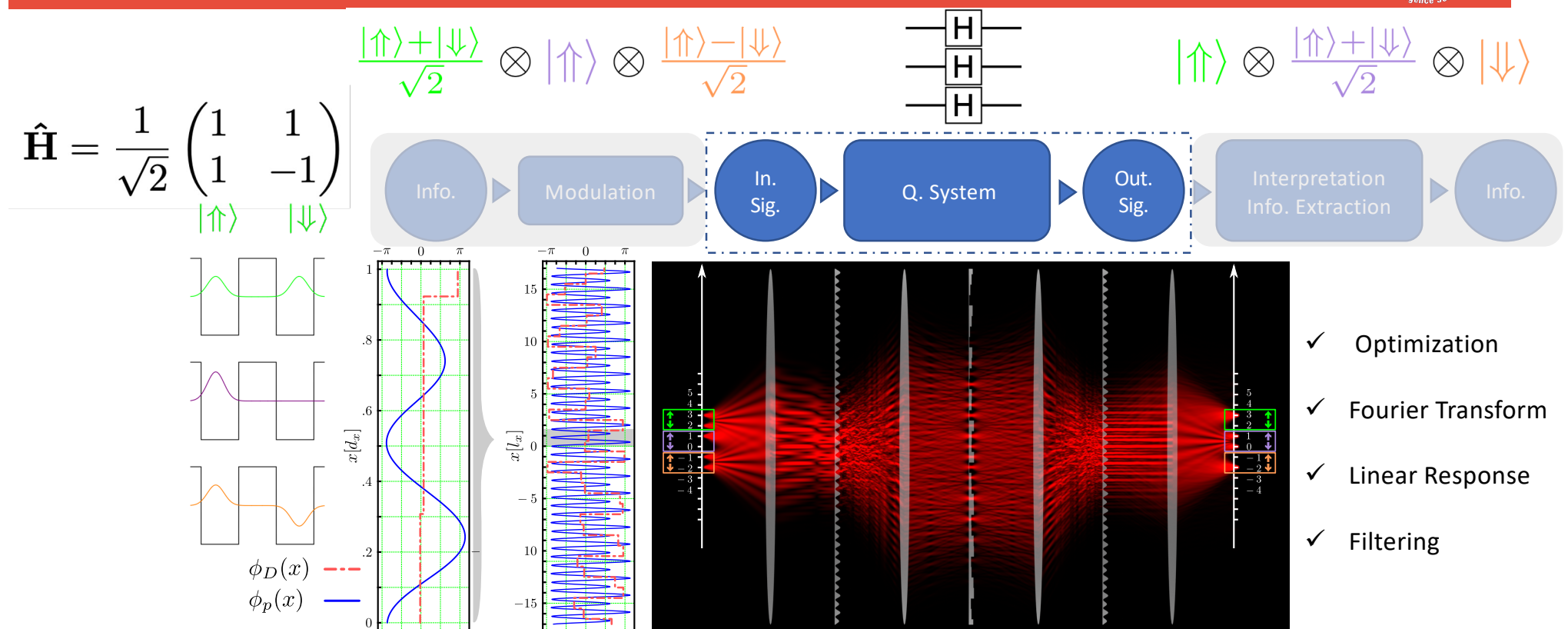
$\frac{|\uparrow\rangle + |\downarrow\rangle}{\sqrt{2}} \otimes |\uparrow\rangle \otimes \frac{|\uparrow\rangle - |\downarrow\rangle}{\sqrt{2}}$

$|\uparrow\rangle \otimes \frac{|\uparrow\rangle + |\downarrow\rangle}{\sqrt{2}} \otimes |\downarrow\rangle$

Quantum Computation via Quantum Fourier Optics



Quantum Computation via Quantum Fourier Optics



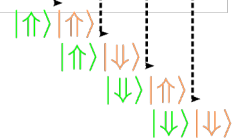
Rezai, Salehi, ArXiv: quant-ph/2303.03877 (2023)

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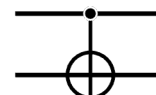
Quantum Computation via Quantum Fourier Optics



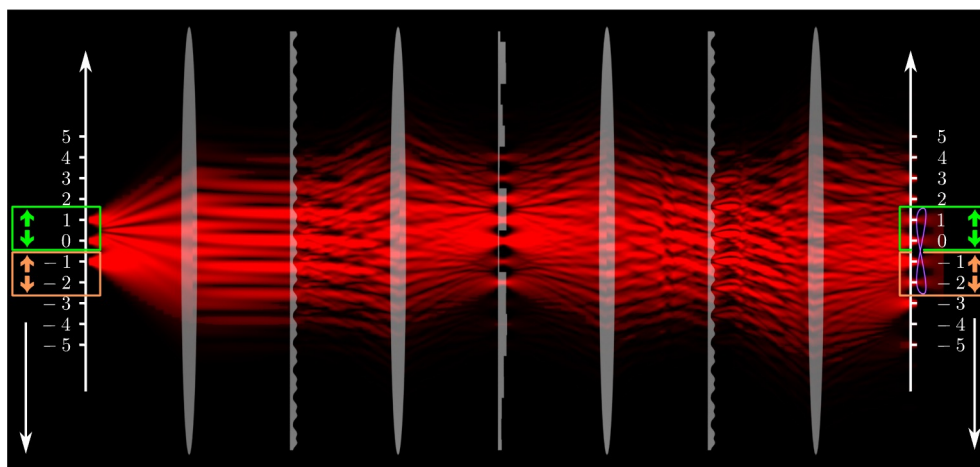
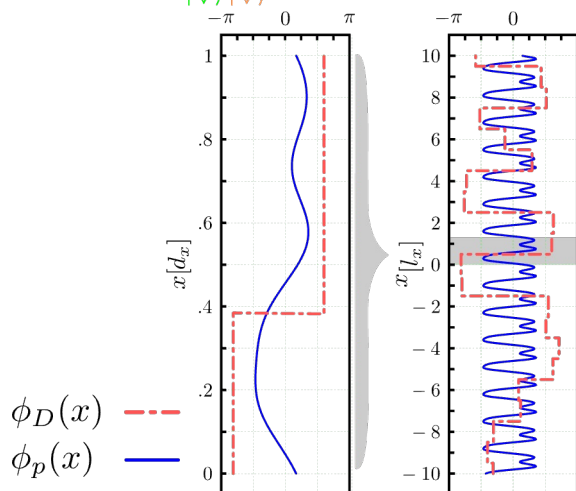
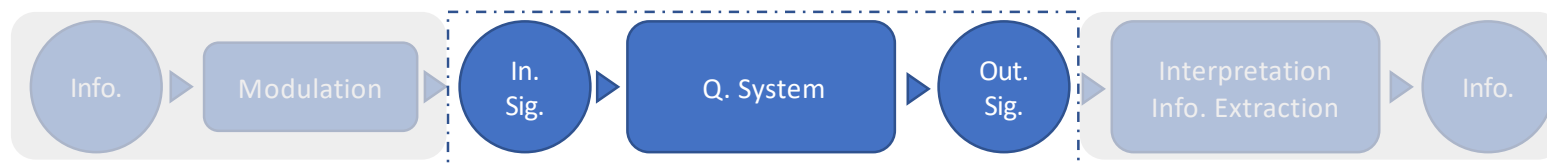
$$\widehat{\text{CNOT}} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$



$$\frac{|\uparrow\uparrow\rangle + |\downarrow\downarrow\rangle}{\sqrt{2}} \otimes |\uparrow\uparrow\rangle$$



$$\frac{|\uparrow\uparrow\rangle|\uparrow\uparrow\rangle + |\downarrow\downarrow\rangle|\downarrow\downarrow\rangle}{\sqrt{2}}$$



- ✓ Optimization
- ✓ Fourier Transform
- ✓ Linear Response
- ✓ Filtering



Thank you

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