Generating Particlelike Scattering States in Wave Transport

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Research Question

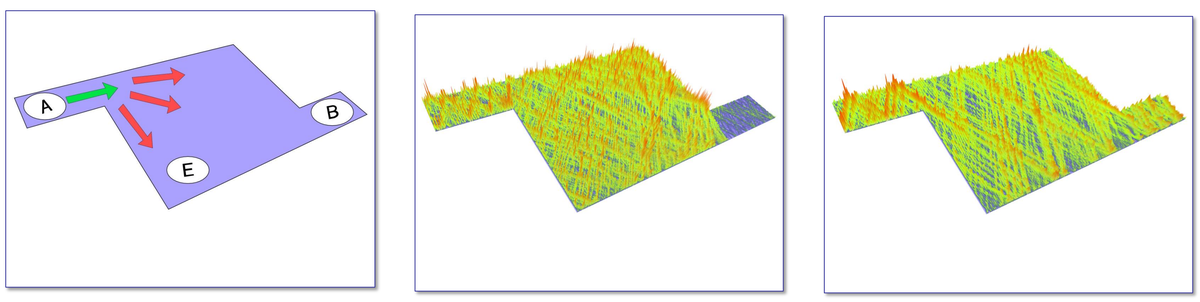
question: how to create particlelike (beamlike) scattering states?

motivation: secure and efficient communication

solution: states with **well-defined time delay**!

- investigated systems: resonator coupled to two wave-guides
- applicable to all waves obeying linear wave equation

Generic Scattering States (Wavelike)



wave injected through left wave-guide

- finite reflection and transmission in general
- wave **spreads** over entire resonator
- **no secure** and **efficient** communication between *A* and *B* without *E* intercepting

Scattering Matrix and Time Delay

$$S = \begin{pmatrix} r & t' \\ t & r' \end{pmatrix}$$

r... reflection matrix

t... transmission matrix

scattering matrix **connects incoming** and **outgoing channels**

Wigner & **Smith**: information about **duration** of scattering event **from phase derivative**[2,3]

e.g.: $t_{mn} = |t_{mn}| e^{i\varphi^t_{mn}} \rightarrow \tau = \hbar \frac{d\varphi^t_{mn}}{dE}$

$$Q = i\hbar \frac{dS^\dagger}{dE} S$$

delay in transmission due to scattering in resonator

Wigner-Smith time delay operator

Algorithm to Generate Particlelike States[1]

$$Q\vec{q} = i\hbar \dot{S}^\dagger S \vec{q} \equiv \begin{pmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \end{pmatrix} \vec{q} = \tau \vec{q}$$

eigenstates of Wigner-Smith time delay operator **injected only** through **left** wave-guide

$$Q \begin{pmatrix} \vec{v} \\ 0 \end{pmatrix} = \begin{pmatrix} Q_{11}\vec{v} \\ Q_{21}\vec{v} \end{pmatrix} = \tau \begin{pmatrix} \vec{v} \\ 0 \end{pmatrix}$$

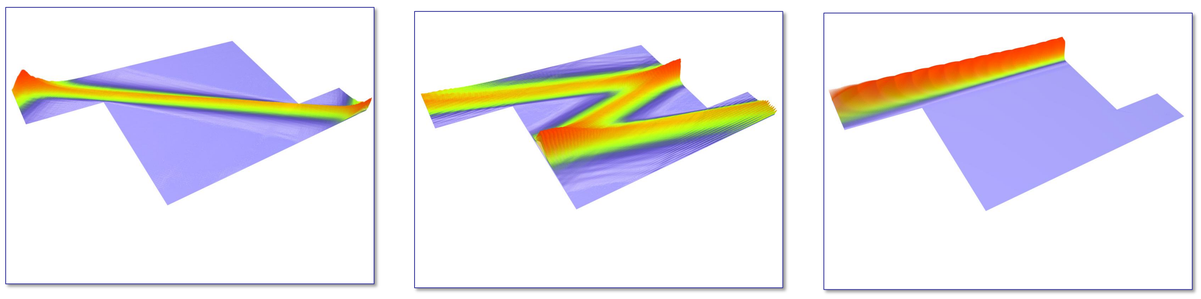
$$\rightarrow \quad Q_{11}\vec{v} = \tau\vec{v}, \quad Q_{21}\vec{v} = 0$$

conditions

- **diagonalize** Q_{11}
- **Identify eigenstates of** Q_{11} **in kernel of** Q_{21}

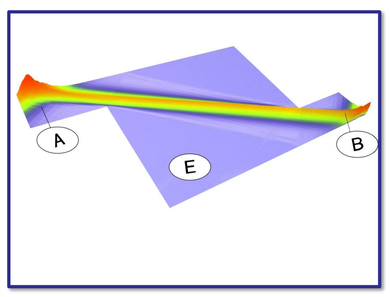
procedure

Results of Numerical Simulation



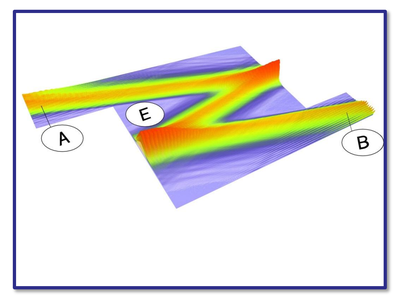
- waves are either fully transmitted or fully reflected
- waves do **not spread**, stay **collimated beams**
- waves on bundles of **particle-trajectories** with similar time delays

Secure Communication



secure communication between *A* and *B* **without *E* intercepting**

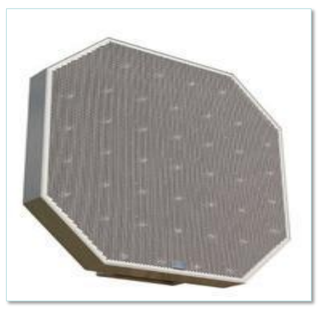
E intercepts: *A* and *B* **switch to another** secure **channel**



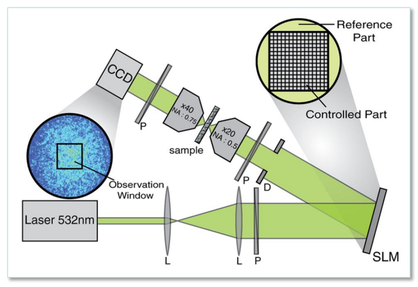
Envisioned Experimental Realizations

scattering matrix **experimentally accessible**[4,5]

setups enabling experimental realization of **particlelike states**



loudspeaker arrays for acoustic waves



spatial light modulators (SLM) for optical waves

antenna arrays for microwave resonators

Summary

- **time delay operator** to generate particlelike scattering states as **eigenvectors**
- **algorithm** can be implemented in **experiment**
- states lie on bundles of trajectories, stay **collimated beams**
- possible applications in **secure** and/or **low power communication**

References

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[2] E.P. Wigner, Phys. Rev. **98**, 145 (1955)

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[4] S.M. Popoff, G. Lerosey, R. Carminati, M. Fink, A.C. Boccara, S. Gigan, Phys. Rev. Lett. **104**, 100601 (2010)

[5] O. Dietz, U. Kuhl, H.-J. Stöckmann, N.M. Makarov, F.M. Izrailev, Phys. Rev. B **83**, 134203 (2011)

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