# The power of photons: Cavity-mediated energy transfer between quantum devices

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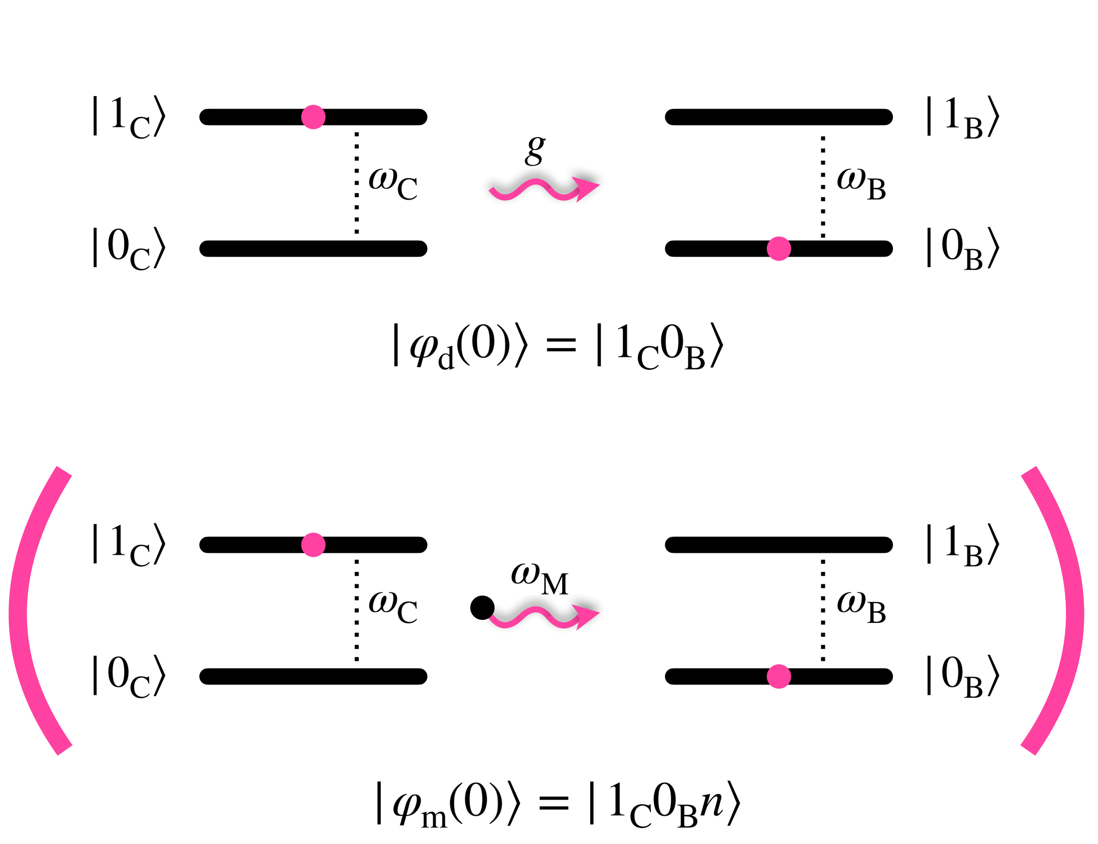
## Abstract

We investigate the coherent energy transfer between two quantum systems mediated by a quantum bus [1, 2]. In particular, we consider the energy transfer process between two qubits, and how it can be influenced by using a resonant cavity as a mediator. Inspecting different figures of merit and considering both on and off-resonance configurations, we characterize the energy transfer performances. We show that the cavity-mediated process is progressively more and more efficient as function of the number of photons inside the cavity acting as a quantum bus [1]. The speeding-up of the energy transfer time, due to a quantum mediator paves the way for new architecture designs in quantum technologies and energy based quantum logics [3].

## Direct vs cavity-mediated energy transfer

It is possible to demonstrate that the energy transfer between a quantum charger and a quantum battery (QB) can be improved adding a cavity as a mediator, even when the system is off-resonance.

## Setups




## Models

The Hamiltonian for a direct energy transfer between a full charger and an empty QB is*

$$H_d^{(t)} = \frac{\omega_C}{2}\sigma_z^C + \frac{\omega_B}{2}\sigma_z^B + g f(t)(\sigma_+^C\sigma_-^B + \sigma_-^C + \sigma_+^B). \quad (1)$$

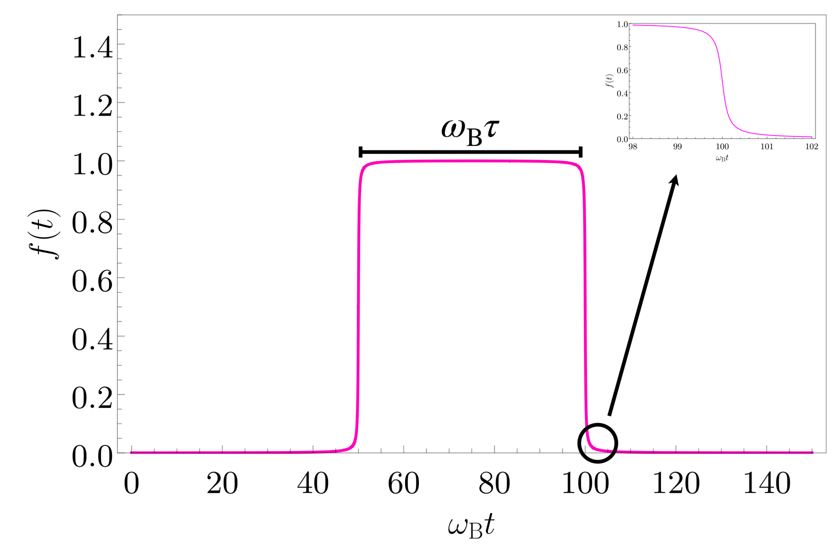
The Hamiltonian for a cavity-mediated energy transfer between a full charger and an empty QB is*

$$\begin{aligned} H_m^{(t)} &= \frac{\omega_C}{2}\sigma_z^C + \frac{\omega_B}{2}\sigma_z^B + \omega_M a^\dagger a \\ &+ g f(t)(a^\dagger\sigma_-^C + a\sigma_+^C + a^\dagger\sigma_-^B + a\sigma_+^B). \end{aligned} \quad (2)$$

*In rotating-wave approximation ($g \lesssim 0.1\omega_{C,B}$).

## Switch on and off function

$$f(t) = \frac{\arctan\left(\frac{t-\tau}{t_0}\right) - \arctan\left(\frac{t-2\tau}{t_0}\right)}{2\arctan\left(\frac{\tau}{2t_0}\right)} \quad (3)$$



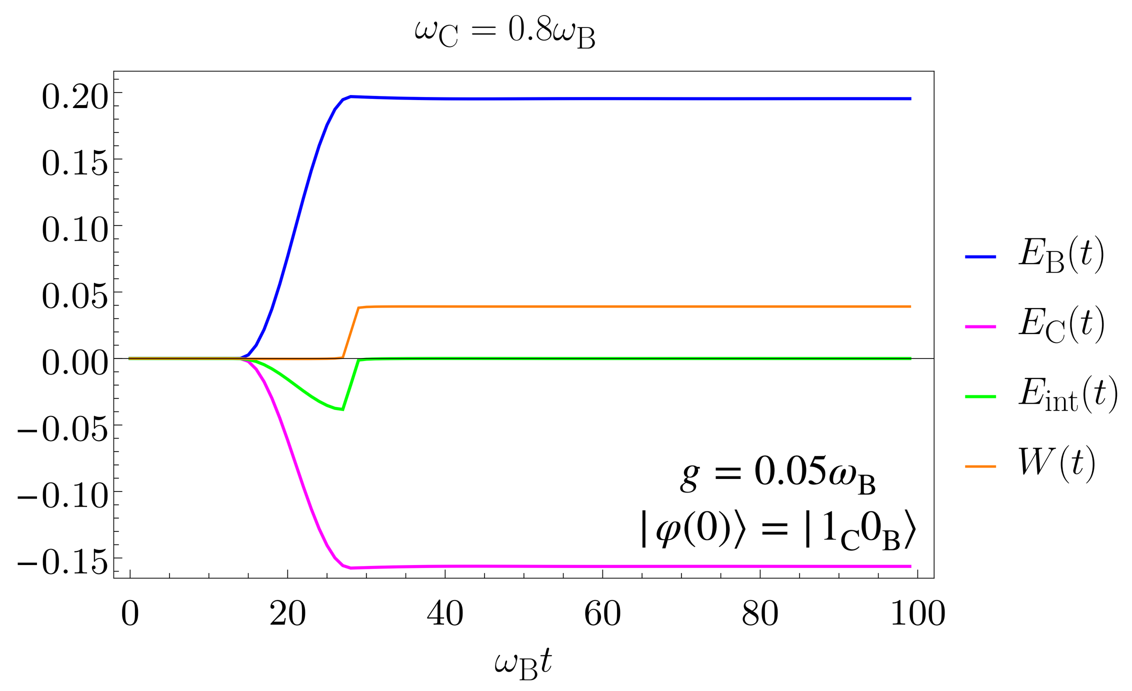

## Direct vs Cavity-mediated off-resonance transfer

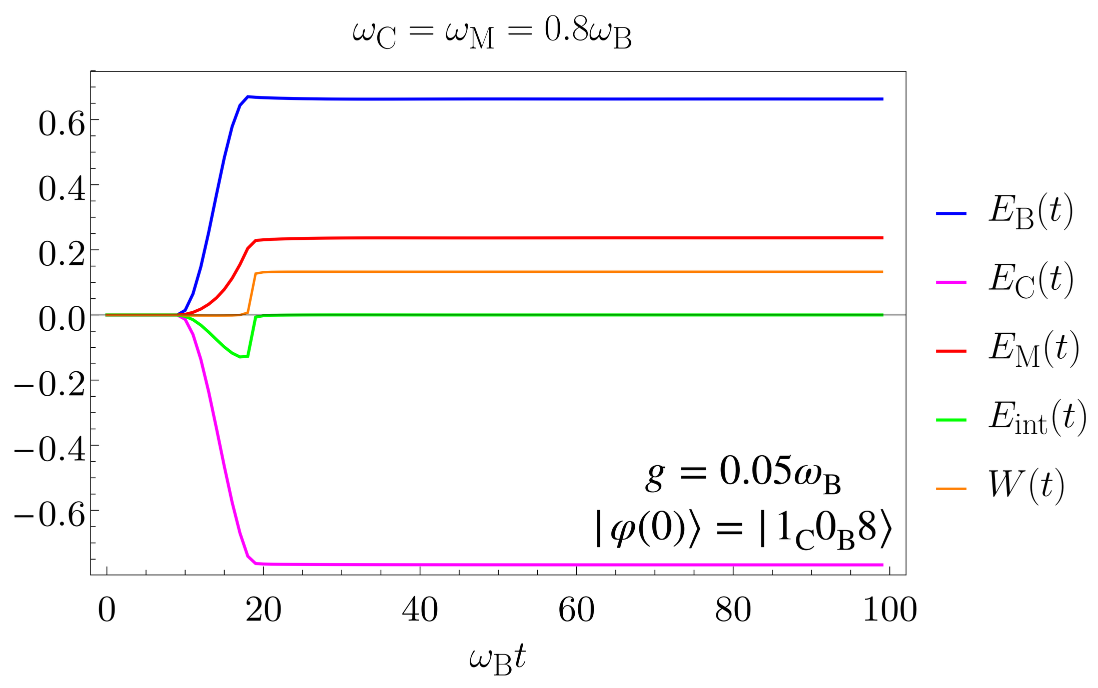
Energy stored in the different parts of the system (i=C,B,M,int):

$$E_i(t) \equiv \langle\varphi(t)|H_i|\varphi(t)\rangle - \langle\varphi(0)|H_i|\varphi(0)\rangle. \quad (4)$$

Work done switching on and off the interaction:

$$W(t) \equiv \int_0^t dt' P(t') = E_C(t) + E_B(t) + E_M(t) + E_{int}(t). \quad (5)$$



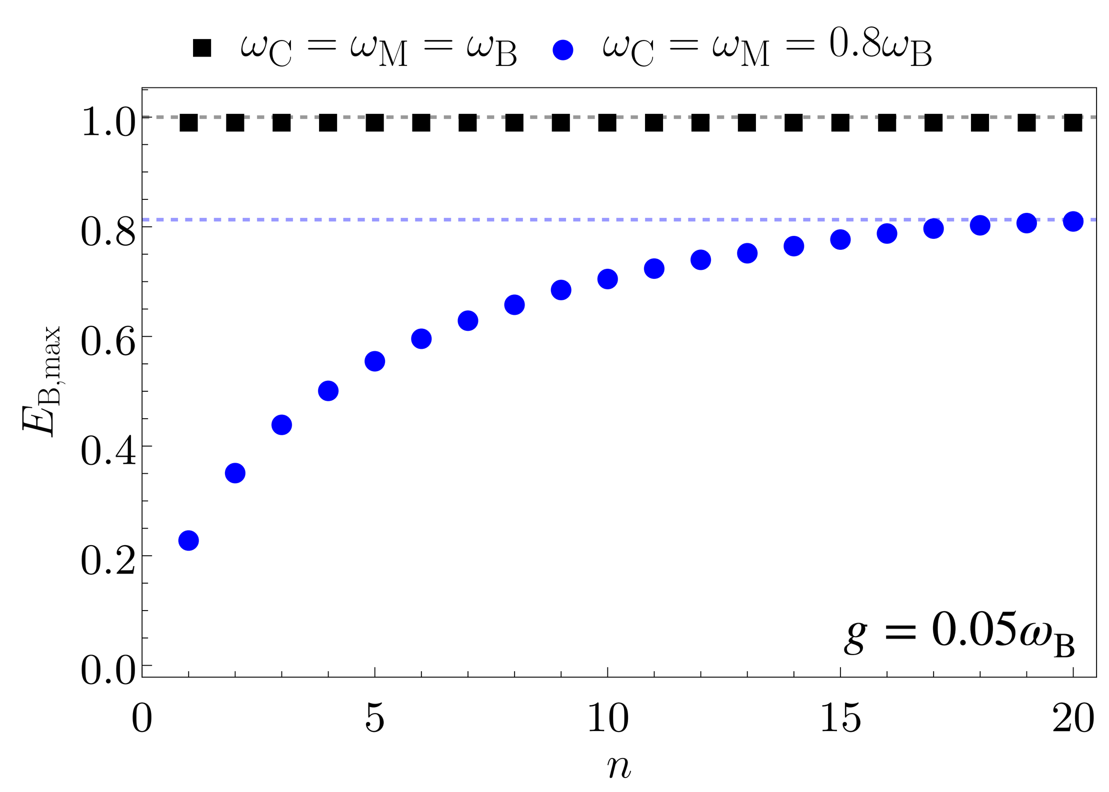

- Faster charging in the cavity-mediated scenario.
- Improved off-resonance energy transfer thanks to the addition of the cavity.

## The power of photons

Maximum of the stored energy inside the QB:

$$E_{B,max} \equiv E_{t_{B,max}}, \quad (6)$$

obtained at the shorter transfer time $t_{B,max}$.




The more photons inside the cavity the more energy is transferred off-resonance.

## Future Perspectives

Study a cavity-mediated energy transfer at higher coupling (without the rotating-wave approximation) and in presence of dissipation regarding the cavity but also the quantum charger and QB.

## Bibliography

[1] A. Crescente, D. Ferraro, M. Carrega, M. Sassetti, *Enhancing coherent energy transfer between quantum devices via a mediator*, Phys. Rev. Research **4**, 033216 (2022).

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[3] P. Scarlino et *al.*, *Coherent microwave-photon-mediated coupling between a semiconductor and a superconducting qubit*, Nature Comm. **10**, 3011 (2019).