$$\frac{\partial}{\partial t}\rho = -\frac{i}{\hbar}[H,\rho] + \mathcal{L}_{\mathrm{nonh.}}[\rho]$$

$$H = H_S + H_E = H_S + \sum_{k=1}^{N_E} H_E^k,$$

H_S

$$H_E$$

$$N_E$$

k

$$\mathcal{L}_{nonh.}[\rho] = \mathcal{L}_S[\rho] + \mathcal{L}_E[\rho] = \mathcal{L}_S[\rho] + \sum_k \mathcal{L}_E^k[\rho]$$

$$t_l = t_a + l\Delta t$$

$$t_n = t_a + n\Delta t = t_e$$

$$\rho_{\alpha_n} = \sum_{\substack{\alpha_{n-1}\ldots\alpha_0 \\ \tilde{\alpha}_n\ldots\tilde{\alpha}_1}} \mathcal{I}^{(\alpha_n\tilde{\alpha}_n)\ldots(\alpha_1\tilde{\alpha}_1)} \left(\prod_{l=1}^{n} \mathcal{M}^{\tilde{\alpha}_l\alpha_{l-1}} \right) \rho_{\alpha_0},$$

$$\rho_{\alpha_l} = \rho_{\nu_l \mu_l}$$

l

$$\mathcal{M} = \exp(-(i/\hbar)[H_S,\,.\,]\Delta t + \mathcal{L}_S[\,.\,]\Delta t)$$

I

ν_l

μ_l

$$\alpha_l = (\nu_l, \mu_l)$$

$$\mathcal{I}^{(\alpha_n,\tilde{\alpha}_n)(\alpha_{n-1},\tilde{\alpha}_{n-1})\ldots(\alpha_1,\tilde{\alpha}_1)} = \sum_{d_{n-1}\ldots d_1} \mathcal{Q}^{(\alpha_n,\tilde{\alpha}_n)}_{1d_{n-1}} \mathcal{Q}^{(\alpha_{n-1},\tilde{\alpha}_{n-1})}_{d_{n-1}d_{n-2}} \ldots \mathcal{Q}^{(\alpha_1,\tilde{\alpha}_1)}_{d_1 1}.$$

$\mathcal{Q}$

d_l

x_l

σ_i

$\sigma_i < \epsilon\sigma_0$

σ_0

$$\mathcal{Q}_{d_l,d_{l-1}}^{(\alpha_l,\tilde{\alpha}_l)} = \sum_{d'_l,d''_{l-1}} \mathcal{T}_{d_l,d'_l} \left(e^{-(i/\hbar)[H_E,\,.\,]\Delta t + \mathcal{L}_E[\,.\,]\Delta t} \right)_{d'_l,d''_l} \mathcal{T}^{-1}_{d''_{l-1},d_{l-1}},$$

T

$\mathcal{T}^{-1}$

$$\rho_{\alpha_l} = q_{d_l}\big(\mathcal{Q}^{(\alpha_l,\tilde{\alpha}_l)}_{d_l,d_{l-1}}\mathcal{M}^{\tilde{\alpha}_l,\alpha_{l-1}}\big)\dots\big(\mathcal{Q}^{(\alpha_2,\tilde{\alpha}_2)}_{d_2,d_1}\mathcal{M}^{\tilde{\alpha}_2,\alpha_1}\big)\big(\mathcal{Q}^{(\alpha_1,\tilde{\alpha}_1)}_{d_1,1}\mathcal{M}^{\tilde{\alpha}_1,\alpha_0}\big)\rho_{\alpha_0},$$

α_l

$$\tilde{\alpha}_l$$

q_{d_l}

$t_l < t_n$

$\mathcal{M}$

$$\left(\mathcal{P}^{(\alpha_l,\alpha_l')}_{e_l,e_{l-1}}\,\mathcal{Q}^{(\alpha_l',\tilde{\alpha}_l)}_{d_l,d_{l-1}}\mathcal{M}^{\tilde{\alpha}_l,\alpha_{l-1}}\right)$$

$$\left(\mathcal{M}^{\tilde{\alpha}_l,\alpha'_l}\mathcal{Q}^{(\alpha'_l,\tilde{\alpha}_l)}_{d_l,d_{l-1}}\mathcal{P}^{(\tilde{\alpha}_l,\alpha_{l-1})}_{e_l,e_{l-1}}\right)$$

$$\mathcal{O}(\Delta t^2)$$

$$\mathcal{O}(\Delta t)$$

$$\left(\sqrt{\mathcal{M}}^{\tilde{\alpha}_l,\alpha'_l}\mathcal{Q}_{d_l,d_{l-1}}^{(\alpha'_l,\tilde{\alpha}_l)}\sqrt{\mathcal{M}}^{(\tilde{\alpha}_l,\alpha_{l-1})}\right)$$

$\sqrt{\mathcal{M}}$

q_l

O_l

$$\epsilon \ll 10^{-12}$$

$\sim$

• • •

$$\frac{\partial}{\partial(t/\lambda)}|\psi\rangle = (\lambda H)|\psi\rangle$$

j

i

d

$$i, j = 0, 1, \ldots, d - 1$$

σ_y

$$\langle \hat{A} \rangle = \mathrm{Tr}_S(\hat{A}\rho_S)$$

ρ_S

$$\hat{A}$$

$$H_S = 0$$

$$H_S = (\hbar/2)(|X\rangle\langle G| + |G\rangle\langle X|)$$

γ

A

$$\gamma\mathcal{L}[A](\rho) = \gamma\left[A\rho A^\dagger - \frac{1}{2}\left(A^\dagger A\rho + \rho A^\dagger A\right)\right].$$

$$t_c = 10$$

$$\tau_{FWHM} = 1$$

$$A = 1\pi$$

$$\delta = 0$$

$$\hat{d} = |1\rangle\langle 0|$$

$$H_D = \frac{\hbar}{2}\left(f(t)\hat{d} + f^*(t)\hat{d}^\dagger\right) \text{ with } f(t) = \frac{A}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\frac{(t-t_c)^2}{\sigma^2}} e^{-i(\delta/\hbar)t}, \quad \sigma = \tau_{FWHM}/\sqrt{8\ln(2)}.$$

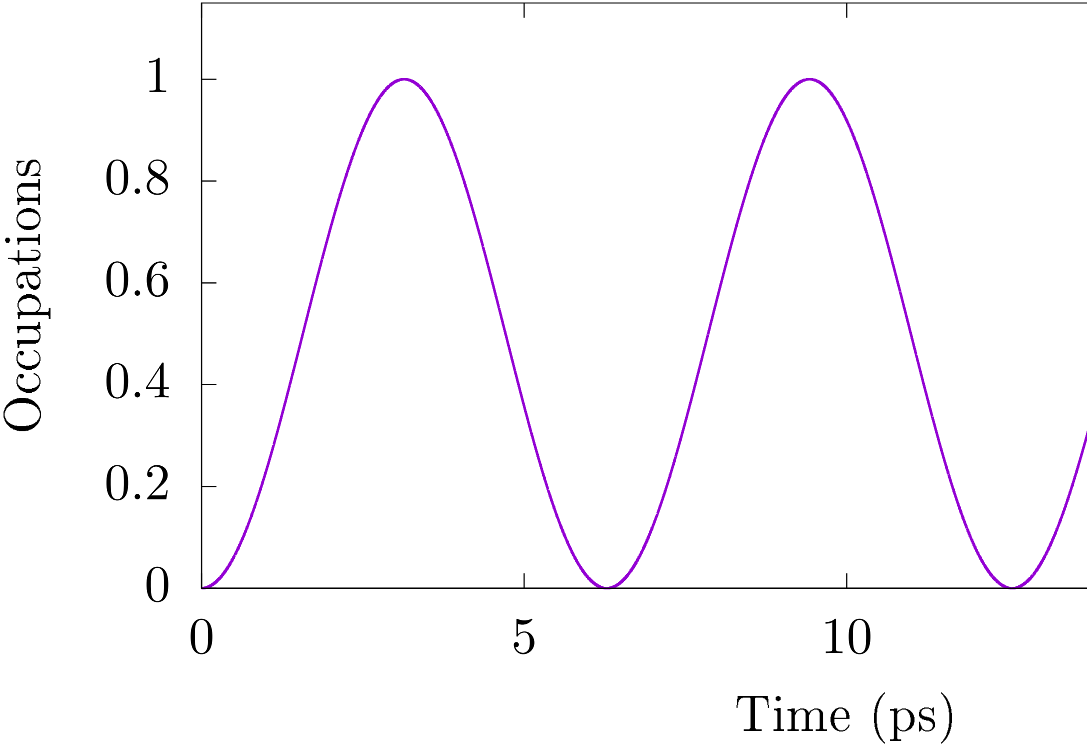
$$f(t)$$

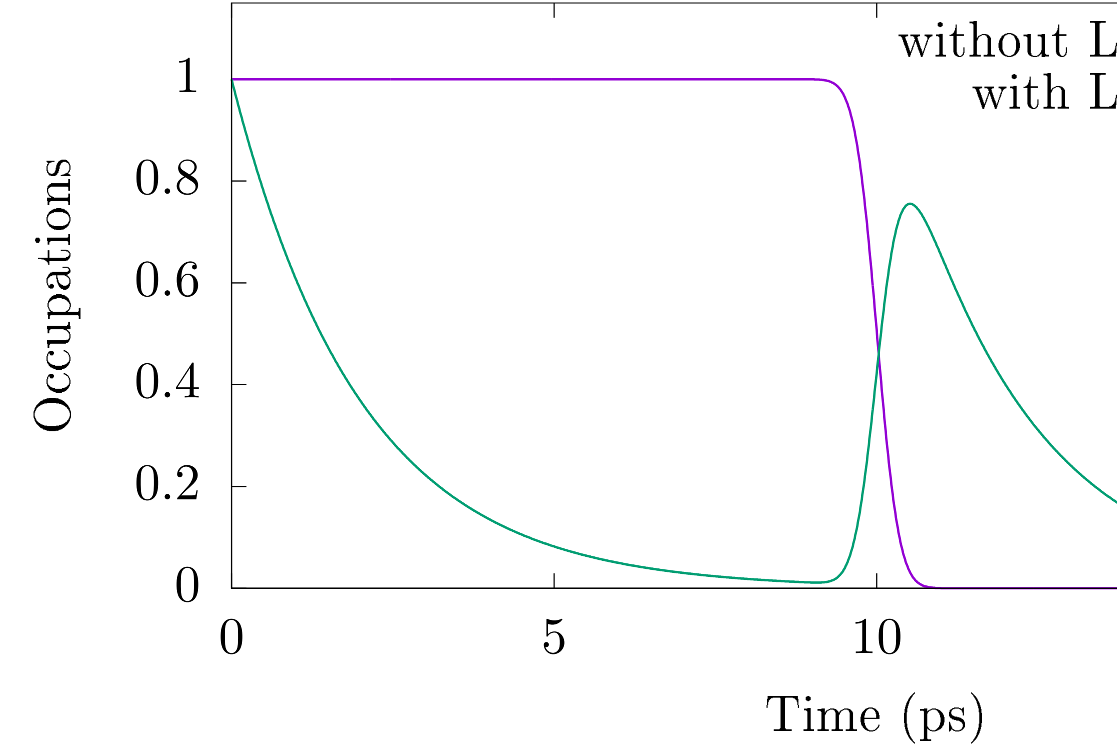
$-\infty$

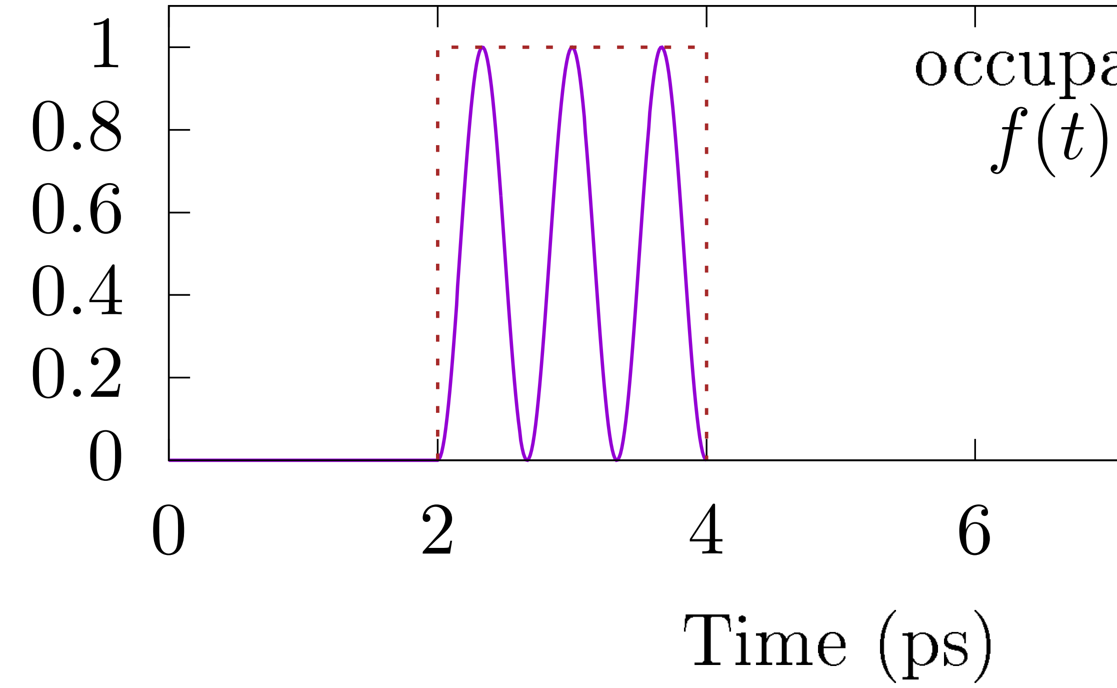
∞

3π

6π


Occupations
1
0.8
0.6
0.4
0.2
0
0
5
10
Time (ps)


without L
with L
Occupations
1
0.8
0.6
0.4
0.2
0
0
5
10
Time (ps)



1
0.8
0.6
0.4
0.2
0
0
2
4
6
Time (ps)
occupa
$f(t)$

$\epsilon\sigma_0$

$$\epsilon = 10^{-7}$$

$$H_E^k = \hbar g\left(c_k^\dagger c_S + c_S^\dagger c_k\right) + \hbar\omega_k c_k^\dagger c_k$$

$$|1\rangle = c_S^\dagger |0\rangle$$

$|0\rangle$

$$c_S^\dagger$$

c_S

$$c_k^\dagger$$

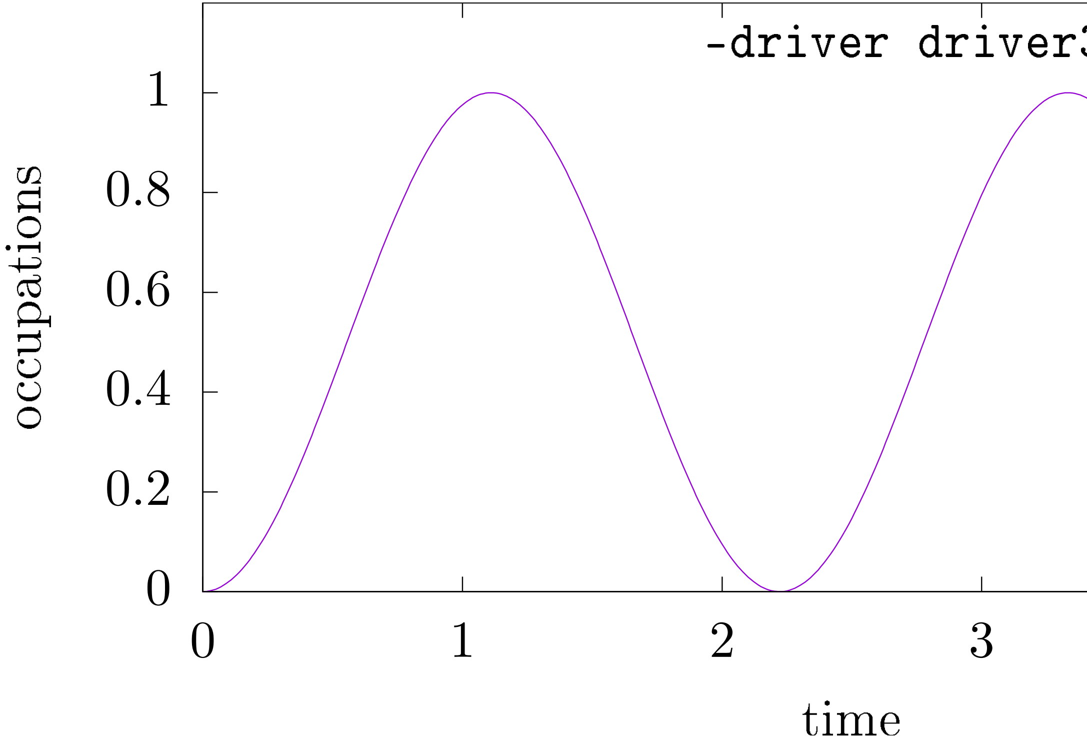
c_k

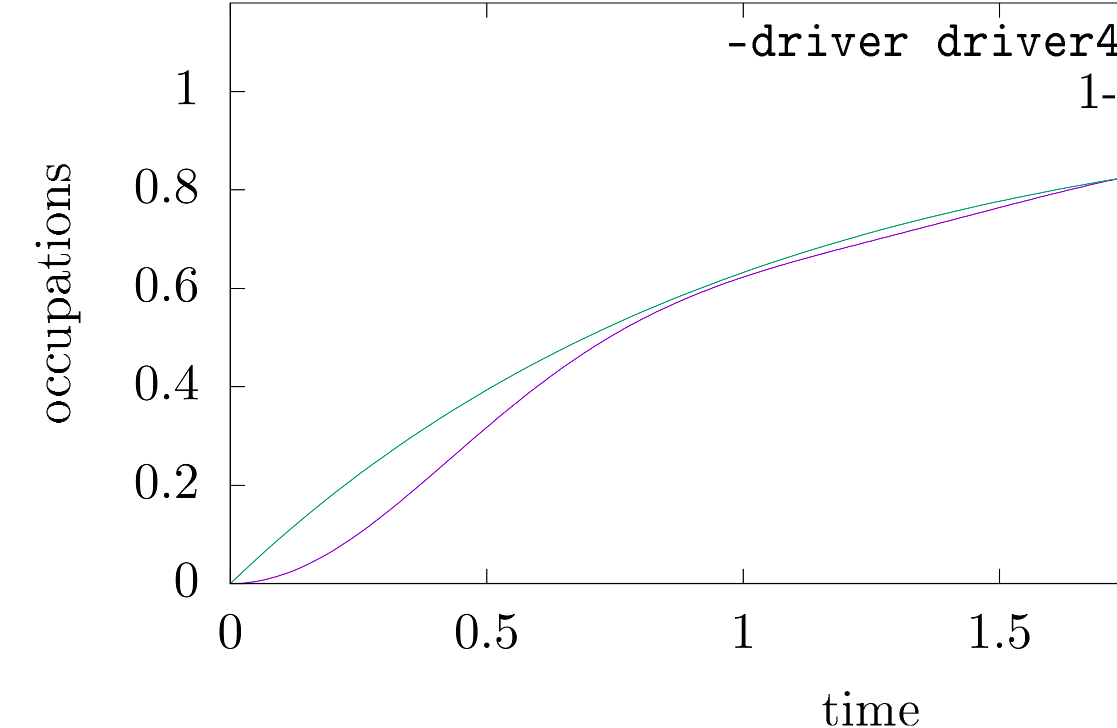
$$N_E \to \infty$$

$$N_E = 10$$

g

$$1 - \exp(-x)$$


-driver driver3
occupations
time
0
0.2
0.4
0.6
0.8
1
0
1
2
3



-driver driver4
1-
occupations
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
time

$$H_E = \sum_{\mathbf{k}} \left[\hbar\omega_{\mathbf{k}} a^\dagger_{\mathbf{k}} a_{\mathbf{k}} + \hbar g_{\mathbf{k}} \big(a^\dagger_{\mathbf{k}} \hat{O}_{sys} + a_{\mathbf{k}} \hat{O}^\dagger_{sys} \big) \right].$$

$$\hat{O}_{sys} = |1 >< 1|_2$$

$$\hat{O}_{sys} = |0 >< 1|_2$$

M

$M - 1$

$$M = 2$$

$$\langle(|1\rangle\langle 1|)\rangle = \exp(-t)$$

$$(\hbar\omega + E_{shift})n$$

$$E_{shift}$$

ω

$\hbar$

g_k

$$E_k = \hbar\omega_k$$

E_k

ω_k

$$J(\omega) = \sum_k g_k^2 \delta(\omega - \omega_k)$$

$$2\pi J(\omega)$$

ω_i

$J(\omega_i)$

$$J(\omega)$$

$$1/(2\pi)$$

$$2\pi J(\omega) = 2\pi(1/(2\pi)) = 1$$

$$J(\omega) = \alpha \omega^s H(\omega),$$

s

$$s = 1$$

$s < 1$

$$s > 1$$

$$\alpha$$

$$H(\omega)$$

$$H(\omega) = exp(-\omega/\omega_c)$$

$$\omega_c$$

$$H_E = \sum_{\mathbf{q}} \left[\hbar\omega_{\mathbf{q}} b^\dagger_{\mathbf{q}} b_{\mathbf{q}} + \hbar\gamma_{\mathbf{q}} \big(b^\dagger_{\mathbf{q}} + b_{\mathbf{q}} \big) |X\rangle\langle X| \right],$$

$$b_{\mathbf{q}}^{\dagger}$$

$b_{\mathbf{q}}$

q

$$s = 3$$

$$\mathcal{Q}_{d_l d_{l-1}}^{(\alpha_l, \tilde{\alpha}_l)}$$

$(\alpha_l, \tilde{\alpha}_l)$

$$\mathcal{Q}_{d_l d_{l-1}}^{(\alpha_l, \tilde{\alpha}_l)} = 0$$

$$\alpha_l \neq \tilde{\alpha}_l$$

$$2^2$$

$$2^4$$

$$\Delta E_p = -\sum_{\mathbf{q}}(\gamma_{\mathbf{q}}^2)/(\omega_{\mathbf{q}}) = -\int_0^\infty d\omega\, J(\omega)/d\omega$$