Rotating Wave Approximation for QOC

Ben Rosand
IBM Quantum
Quantum Intern – Pulse Team
Yorktown Heights, NY

September 2, 2020

Abstract

This is the paper's abstract ...

1 Introduction

This is time for all good men to come to the aid of their party!

Outline The remainder of this article is organized as follows. Section 2 gives account of previous work. Our new and exciting results are described in Section 3. Finally, Section 6 gives the conclusions.

2 Previous work

A much longer LaTeX 2_ε example was written by Gil [**?**].

3 Results

In this section we describe the results.

4 Rotating Wave Approximation

4.1 Single rotation

We follow the template laid out in [CITE FIscher] to perform the rotating wave approximation for an N-level system with one control field. For starters, we take the laboratory frame Hamiltonian [CITE FISCHER]

$$H_{lab} = H_0 + \sum_{m=1}^{M} \Omega_m \cos(\omega_m t + \phi_m) \sum_{n'>n} g_{nn'} \sigma^x_{nn'} \tag{1}$$

This generalized hamiltonian maps perfectly to our systems, with H_0 representing all of our time independent elements. g_{nn} represents the prefactors on various drive terms (represented in our printed hamiltonians as Ω_n).

Sometimes we can ignore certain transitions because they are off-resonance. I would think this would apply to the transitions to the 2 state for our systems, but need to DOUBLE CHECK.

The first replacement is the basic RWA, replacing the driving terms with the terms from the RWA (FISCHER 3.25). also let $S = (n, n')$ which are on resonance and allowed.

$$H_{lab} \approx H_0 + \frac{\Omega}{2} \sum_{S} g_{nn'} \cos(\omega t + \phi) \sigma^x_{nn'} - \sin(\omega t + \phi) \sigma^y_{nn'}) \tag{2}$$

Our goal here is to get rid of the oscillation ωt. Again from fischer the desired transformation is:

$$|\psi\rangle_{rot} = e^{-iR} |\psi\rangle_{lab} \tag{3}$$

We take the derivative and obtain an equation for the transformed Hamiltonian:

$$H_{rot} = e^{iR} H_{lab} e^{-iR} + \frac{\mathrm{d}R}{\mathrm{d}t} \tag{4}$$

From this equation, our goal is to find R. The core of the RWA is the following transformation:

$$e^{-iR} \left\{ \cos(\omega t + \phi) \sigma^x_{nn'} - \sin(\omega t + \phi) \sigma^y_{nn'} \right\} e^{iR} = \cos(\phi) \sigma^x_{nn'} - sin(\phi) \sigma^y_{nn'} \tag{5}$$

This transformation is applied over the set S in the sum in (2). The final step to the transformation is to find R such that these transformations hold. With that R in hand, we can see that (4) evaluates to

$$H_{rot} = H_0 + \frac{\mathrm{d}R}{\mathrm{d}t} + \frac{1}{2}\Omega \sum_{S} g_{nn'} \left\{\cos\phi\sigma^x_{nn'} - sin\phi\sigma^y_{nn'}\right\} \tag{6}$$

This is the rotating frame Hamiltonian, the key difference being the lack of oscillation on ω (carrier frequency), which is moved into the "generalised detuning term" $H_0 + \frac{\mathrm{d}R}{\mathrm{d}t}$. Note that in the two-level case this term reduces to $\frac{1}{2}\delta\omega\sigma^z$

What does equation (6) look like for IBM Q devices? All variables can be fillled in except for R, which can be solved through another process which will be shown after.

$$H_0 = H_d + H_{coupling} + H_{occupation_operator} \tag{7}$$

$$\Omega = \Omega_{d,i} \qquad \text{Note that this transformation is for only one drive} \tag{8}$$

$$g_{nn'} = 1 \tag{9}$$

$g_{nn'}$ is technically contained in Ω because we are off resonance so only concerned with 0 to 1 transition

4.2 Determining transformation matrix R

The matrix R is derived from equation (5). The two relationships that Fischer uses to make this derivation are the fact that R and $\sigma^z_{nn'}$ commute.

4.3 Multiple drives and rotations

5 New RWA

6 Conclusions

We worked hard, and achieved very little.