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Quantum Computing Architecture and Hardware for Engineers - Step by Step - Volume II

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Contents

Chapter 26
Addenda and Errata of Volume 1

26.1 Introduction

In this Chapter, we will fix some of the typos in Volume 1 [1] and add clarifications. They are ordered according to subsection numbers.

26.2 Addenda and Errata

Section: 12.3.2.2

Location: Page 163, Right before Eq. (12.12). Highlight: Clarification of tensor product.

Therefore, the Hamiltonian of the system, which can be obtained by a tensor product based on the individual Hamiltonians, $\boldsymbol{H_1} \otimes \boldsymbol{I_2} + \boldsymbol{I_1} \otimes \boldsymbol{H_2}$, is

$$\boldsymbol{H} = \begin{pmatrix} -E_z & 0 & 0 & 0 \\ 0 & \frac{-dE_z}{2} & 0 & 0 \\ 0 & 0 & \frac{dE_z}{2} & 0 \\ 0 & 0 & 0 & E_z \end{pmatrix}, \tag{12.12}$$

Section: 17.3

Location: Page 241, Fig. 17.2. Highlight: Typos in Steps 3 and 5 in Fig. 17.2.

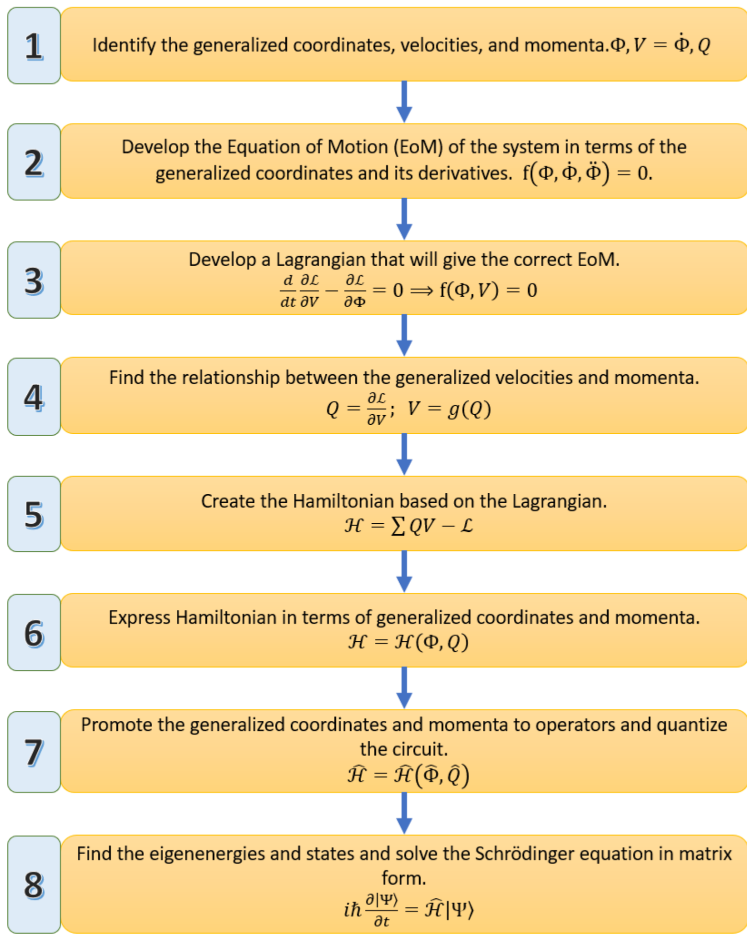

Fig. 17.2 Quantization flow using the electrical circuit as an example

Section: 17.3

Location: Page 246, Steps 5 and 6, Right before Eq. (17.35). Highlight: Integration should be used since the Hamiltonian is time-dependent.

It, thus, adds an additional total phase shift to the unitary matrix constructed from $e^{-\frac{i}{\hbar}\int_0^t \mathcal{H}(t')\,dt'}$.

Section: 23.3.1

Location: Pages 329-331 Highlight: The initial signals and LO signal need to be changed so that the low-pass filter will filter the higher frequency component. The text and Fig. 23.2 are updated accordingly.

Firstly, an "in-phase" (or I) component and an "out-of-phase" (or Q or **quadrature** component) are generated by AWGs (Fig. 23.2). AWGs can generate any (arbitrary) waveform as long as the required frequency is not too high. The I component is

$$-2s(t)I\sin\omega_{AWG}t = -2s(t)\cos\phi\sin\omega_{AWG}t, \tag{23.5}$$

and the Q component is

$$-2s(t)Q\sin\omega_{AWG}t = 2s(t)\sin\phi\sin\omega_{AWG}t, \tag{23.6}$$

where ω_{AWG} is the frequency of the pulses and $s(t)$ is the envolope function. Note that $s(t)$ is scaled by $-2I$ and $-2Q$, respectively, as the final envelope functions of the pulses generated by the AWG in this particular example. Since ω_{AWG} is in the order of tens of MHz (e.g., $50MHz$), it can be generated digitally by the AWGs easily. Note that ϕ is embedded as the amplitude of the I and Q signals.

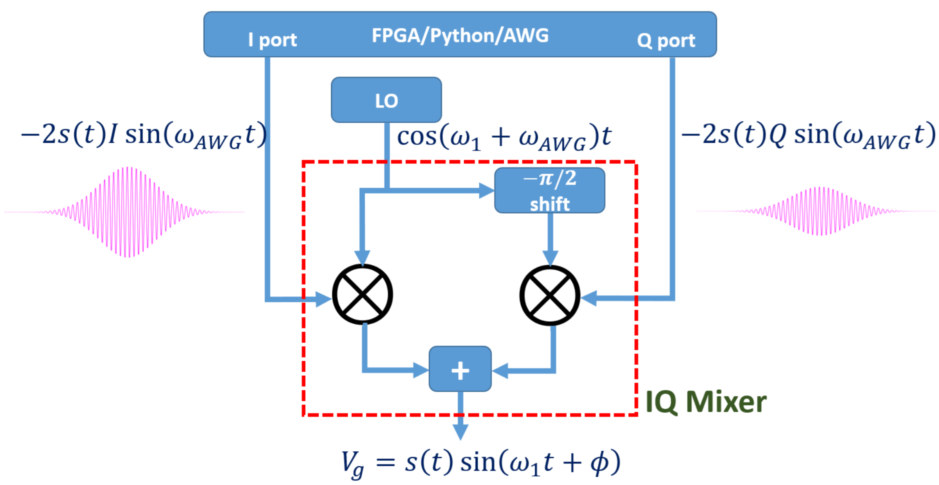

Fig. 23.2 Schematic showing how the I and Q signals generated by AWG are mixed with the LO signal in an IQ mixer to achieve the desired wavefunction for qubit manipulations

However, the pulses we need to interact with the qubits are in GHz. An $I-Q$ mixer is then used to multiply the AWG signals with the signal from a local oscillator to bring it to a high enough frequency. This is called **up-conversion**. The LO generates a high-frequency sinusoidal wave at the GHz range, $\cos(\omega_1 + \omega_{AWG})t$ (e.g., 5 GHz). We assume the amplitude is one for simplicity. Its frequency is chosen to be $\omega_1 + \omega_{AWG}$ because the goal is to achieve a signal with ω_1 at the mixer output. Note that, in an $I - Q$ mixer, the I part is multiplied by the LO signal (in-phase component) directly. The Q component is multiplied by the LO signal phase-shifted by $-\pi/2$ (quadrature component). Note that we make it $-\pi/2$ instead of the commonly used $\pi/2$ because we want to make the final equation in the desired form for instructional purposes. They are then added together as the output.

Therefore, the signal after the $I - Q$ mixer, V_g, is given by

$$\begin{aligned} V_g &= -2s(t)I\sin\omega_{AWG}t\cos(\omega_1 + \omega_{AWG})t \\ &\quad -2s(t)Q\sin\omega_{AWG}t\cos\left((\omega_1 + \omega_{AWG})t - \frac{\pi}{2}\right), \\ &= -2s(t)\cos\phi\sin\omega_{AWG}t\cos(\omega_1 + \omega_{AWG})t \\ &\quad +2s(t)\sin\phi\sin\omega_{AWG}t\sin(\omega_1 + \omega_{AWG})t, \end{aligned} \tag{23.7}$$

where we have used the identity, $\cos(\theta - \pi/2) = \sin\theta$ in the second line. Then, we will use the product formulae, $\sin\alpha\cos\beta = \frac{1}{2}(\sin(\alpha+\beta) + \sin(\alpha-\beta))$ for the first term and $\sin\alpha\sin\beta = \frac{1}{2}(\cos(\alpha-\beta) - \cos(\alpha+\beta))$ for the second term. We get:

$$\begin{aligned} V_g = &-2s(t)\cos\phi\frac{1}{2}(\sin(\omega_1 t + 2\omega_{AWG}t) + \sin(-\omega_1 t)) \\ &+2s(t)\sin\phi\frac{1}{2}(\cos(-\omega_1 t) - \cos(\omega_1 t + 2\omega_{AWG}t)), \end{aligned} \tag{23.8}$$

where the $(2\omega_{AWG}t + \omega_1 t)$ terms will be filtered by a **low-pass filter (LPF)** and the signal becomes:

$$\begin{aligned} V_g &= s(t)\cos\phi\sin\omega_1 t + s(t)\sin\phi\cos\omega_1 t, \\ &= s(t)\sin(\omega_1 t + \phi). \end{aligned} \tag{26.1}$$

Therefore, we have achieved the pulse in Fig. 21.1 for qubit manipulation. More specifically, we only need to set the amplitude of the pulse from the I (Q) port to control the amount of rotation about the x-axis (y-axis) on the Bloch sphere. We can also control the rotation speed $\Omega_R(t)$ by applying an appropriate envelope function $s(t)$ using AWG.

It should be noted that if ω_{AWG} is not large enough, filtering of the $(2\omega_{AWG}t + \omega_1 t)$ terms can be difficult as it is approximately the same as $\omega_1 t$. Then a **single-side band (SSB)** mixer is required, which can achieve the same purpose of keeping only one of the components.

References

1. Hiu-Yung Wong. *Quantum Computing Architecture and Hardware for Engineers*. Springer, 2025.