# Phase noise model for qubit control

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## Introduction

The evolution of superconducting qubits is controlled by means of properly shaped microwave pulses. Such pulses are unavoidably affected by phase noise, which is the consequence of instabilities of the reference oscillators, resulting from various sources of nonidealities. We present an improved approach to the generation of phase noise sequences, that can be used for the numerical simulation of the time evolution of the state of a qubit, in order to analyze and understand the effect of phase noise on the achievable fidelity of quantum gates.

## Numerical method

We have developed the numerical procedure illustrated in Fig. 1 to generate sequences of base-band phase noise values with arbitrarily shaped power spectral density (PSD). We start with the generation of a sequence of pseudorandom noise values with a gaussian amplitude distribution and a white spectrum. We synthesize the finite impulse response of a FIR filter, characterized by the desired frequency behavior (by means of an inverse Fourier transform). Then, the white gaussian noise sequence is convolved with the impulse response to obtain the desired phase noise. To speed up the evaluation of the convolution, we transform it into a multiplication in the frequency domain, exploiting the FFT (Fast Fourier Transform) for the conversion from the time to the frequency domain and vice versa. A proper zero-padding is performed to obtain vector lengths that are a power of 2.

## Results and discussion

In Fig. 2 we report the PSDs for flicker-like phase noise with different corner frequencies, while in Fig. 3 and Fig. 4 we show the phase noise behavior in the time domain (we see that within the duration of a typical experiment the lowest frequency components give a limited contribution, while they are relevant over the longer time interval). To understand the contribution of single frequency components we use gaussian narrow-band filters. In Figs. 5 and 6, we report the impulse response and the frequency response (respectively) for such filters. The effect of control-signal nonidealities on qubit coherence and on error rates has been discussed in the literature by various authors, in particular Ball and Biercuk [1] have performed a Hamiltonian analysis based on the expressions derived by Green et al. [2]. While in Ref. [1] they conclude that higher frequency components of phase noise give the largest contribution, we find, with Qiskit-Dynamics simulation in which we exploit our phase noise sequences, that a well defined spectral interval contributes, depending on the duration of the experiment and coupling with the qubit.

## Acknowledgment

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## References

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[2] T. J. Green, J. Sastrawan, H. Uys, M. J. Biercuk, New J. Phys. vol. 15, 905004 (2013) doi:10.1088/1367-2630/15/9/095004

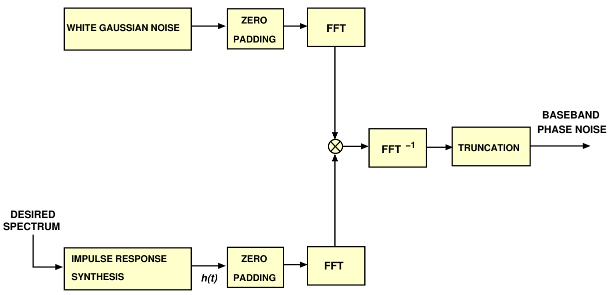


Fig. 1. Block diagram of the numerical procedure to generate baseband phase noise.

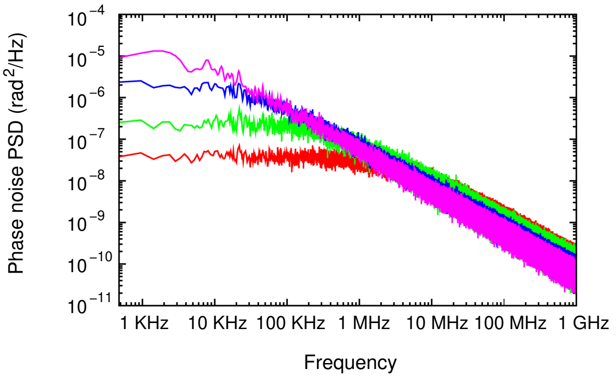


Fig. 2. Flicker phase noise PSD for different corner frequencies: 1.59 kHz (magenta), 15.9 kHz (blue), 159 kHz (green) and 1.59 MHz (red).

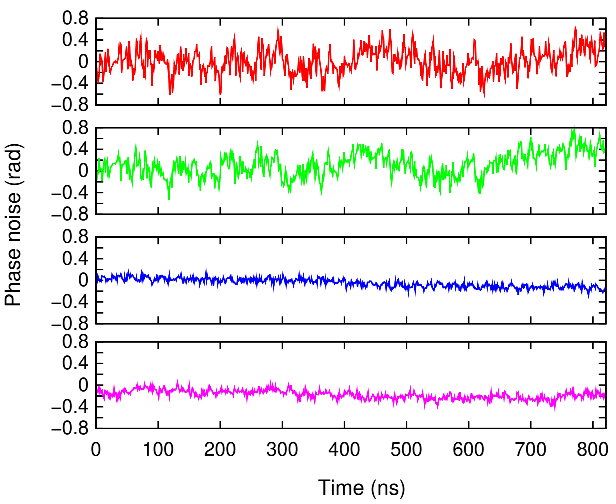


Fig. 3. Phase noise as a function of time, over an interval equal to the duration of the experiment, 820 ns.

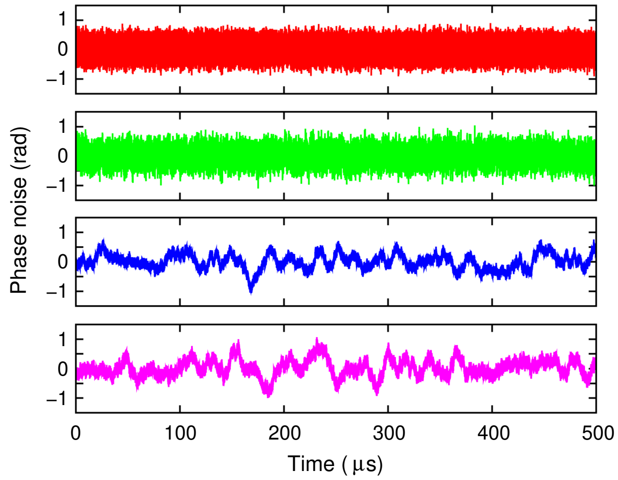


Fig. 4. Phase noise as a function of time, over an interval of 500 $\mu$s.

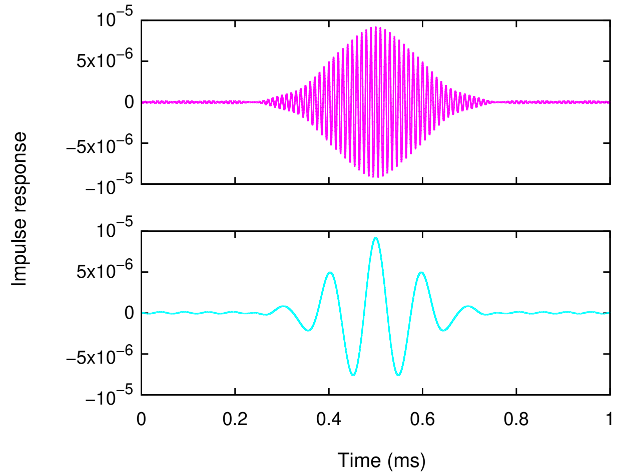


Fig. 5. Impulse response for gaussian filters with the same bandwidth (3 kHz), but different center frequencies: 10 kHz (cyan) and 100 kHz (magenta).

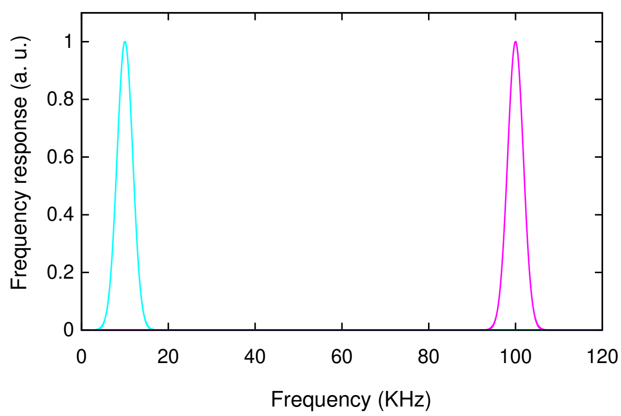


Fig. 6. Frequency response of two gaussian filters centered at 10 kHz (cyan) and at 100 kHz (magenta).