YQuantum: Application Note
"Linear BiasT for Flux-Biasing of Superconducting Qubits"

Introduction

High-fidelity two-qubit gates remain a major bottleneck in state-of-the-art superconducting quantum processors. The performance of these gates is often limited by the hardware setup of the flux control lines. This application note investigates the role of the BiasT circuit in improving the gate fidelity — focusing on its noise-filtering properties and, most importantly, its linearity.

Short voltages pulses precisely tailored on nanosecond timescales are essential for operating superconducting quantum processors and enabling high-fidelity two-qubit gate operations. A typical setup for such operations [1] is shown in Fig. 1, where a BiasT circuit (highlighted in purple) at room temperature is used to combine DC offset and pulsed RF control signals. The DC offset is calibrated to precisely tune the qubit frequency to its "flux sweet spot", and short voltage pulses on the RF control line are employed to activate two-qubit interactions.

When using a low-noise voltage source to generate the DC offset, a precision resistor is required to convert the voltage into a stable control current used for tuning the qubit. A space-efficient solution is to integrate this bias resistor directly into the BiasT circuit, as illustrated in Fig. 1. In this configuration, the total bias resistance seen by the DC source is the sum of the BiasT circuit resistance (1 kΩ) and the load resistance at the RF+DC port (approximately 50 Ω).
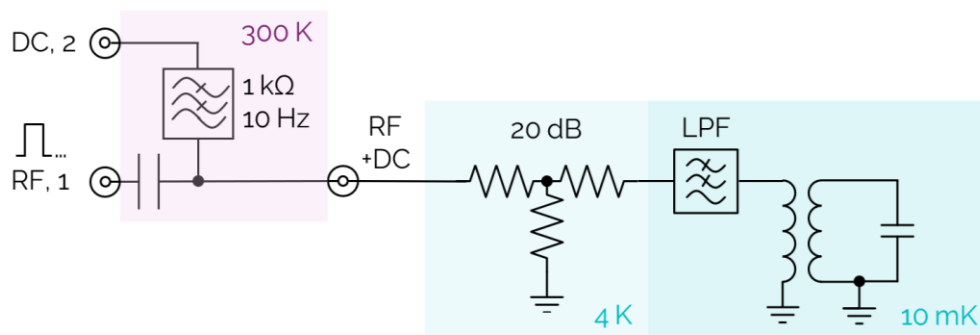

Figure 1 *Typical flux-biasing setup for controlling the frequency of a superconducting qubit. The BiasT (purple) is installed at room temperature to combine the DC offset from a low-noise DC source with the pulsed RF signal from a fast-sampling arbitrary waveform generator (AWG). Inside the cryostat (blue), a 20dB attenuator and a low-pass filter are used to further condition the flux-control signal before it reaches the superconducting qubit.*
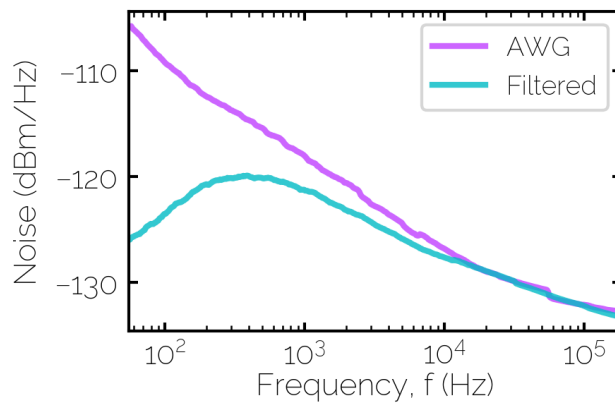
Noise Filtering

Figure 2 *Measurements of the noise spectral density for the output of an AWG with (cyan) and without (purple) filtering through the BiasT.*

The pulsed RF-control signal from a fast-sampling arbitrary waveform generator (AWG) typically contains significant 1/f-noise, as shown in purple in Fig. 2. This noise can limit the coherence of a superconducting qubit connected to the flux-control line, particularly when the qubit is detuned from its "flux sweet spot" during a two-qubit gate operation. The BiasT, which acts as a high-pass filter at the RF input port, effectively reduces this low-frequency noise. As illustrated in Fig. 2, the filtered noise density (cyan) shows strong suppression of noise below 20 kHz. Beyond filtering noise from the AWG, the BiasT also helps mitigate low-frequency noise introduced by ground loops between multiple flux lines. For optimal performance, it is therefore recommended to place the BiasT as close as possible to the cryostat input.

For the DC control signal, an ultra-low-noise DC source should be used in combination with additional filtering inside the BiasT. Here, a low-pass filter with a cutoff frequency of approximately 10 Hz can effectively suppresses unwanted low-frequency noise. Such a low cutoff frequency is suitable for the filtering of the DC signal, as the DC offset is varied only very slowly during qubit frequency calibration. By implementing these noise reduction strategies, we can generate low-noise flux-control signals and are ready to achieve high-fidelity two-qubit gate operations.

Linearity

Due to the high-pass filtering characteristics of the BiasT and other distortions in the flux-control line [2], the fast flux pulses generated by the AWG must be pre-distorted to maintain accurate qubit flux control. To analyze the impact of the BiasT on the flux-control line response, we measure the step response of different BiasTs while varying the pulse amplitude, see Fig. 3.

A key observation is that the response of a commercially available BiasT changes with increasing pulse amplitude, implying non-linearity. This non-linearity hinders the accurate calibration of pre-distortion filters, which are essential for achieving high-fidelity two-qubit gate operations. Although the deviations at large pulse amplitudes appear relatively small, they can certainly become a limiting factor when aiming for two-qubit gate fidelities exceeding 99.0 %.
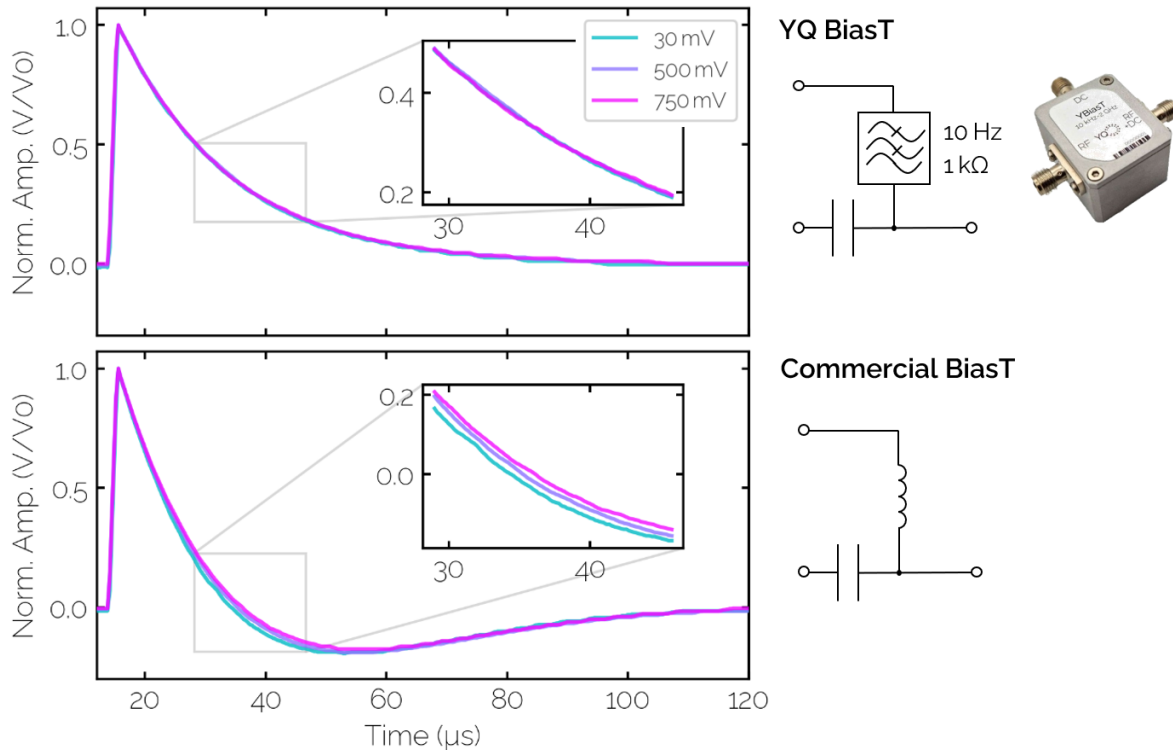
Figure 3 *Step response of the BiasT into a 50 Ω load for (top) the YQ-BT-2G BiasT and (bottom) a commercially available BiasT. The step response is measured for different pulse amplitudes V0, given in the inset in the upper graph, and the normalized responses are shown.*

Furthermore, when comparing the step response of the YQ-BT-2G BiasT to that of the commercial BiasT, a fundamental difference in system behavior emerges. The YQ-BT-2G BiasT exhibits characteristics of a first-order system, whereas the commercial BiasT behaves as a second-order system due to inductors and capacitors being used in the internal circuitry. This second-order behavior makes pre-distortion significantly more challenging.

Summary

This application note has highlighted the importance of noise filtering in flux-control signals for superconducting qubits using a BiasT circuit at room temperature. Additionally, we have investigated the linearity of BiasT circuits and identified that non-linearity can pose a major challenge for accurate qubit flux control. Understanding and mitigating these effects is crucial for achieving high-fidelity two-qubit gate operations.

References

[1] S. Krinner et al., „*Engineering cryogenic setups for 100-qubit scale superconducting circuit systems* ", <u>*EPJ Quantum Technology,*</u> vol. **6**, 2 (2019)

[2] C. Hellings et al., *"Calibrating Magnetic Flux Control in Superconducting Circuits by Compensating Distortions on Time Scales from Nanoseconds up to Tens of Microseconds",* <u>arXiv:2503.04610</u> (2025)