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Implementation of Cryogenic Amplifier by Using Superconducting Nanowire Single Photon Detector

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Abstract: Measuring superconducting materials near absolute zero Kelvin poses challenges due to low output voltage. This study presents a cryogenic amplifier for ultra-low temperatures, fabricable on the same chip as the material, replacing noisy room temperature setups.

1. introduction

Superconducting nanowire single-photon detectors or SNSPDs are made from thin-film superconducting materials. SNSPD is recognized as one of the most promising options for single photon detection, which can be utilized in a range of applications such as quantum computing, Light Detection and Ranging (LIDAR), and imaging. This is attributed to SNSPD's exceptional high efficiencies, low timing jitter and gigahertz counting rates. The performance of superconducting nanowire is influenced by their geometric properties and fabrication qualities, but also by the design of the bias and the readout circuit. In this study, we introduce a cryogenic amplifier designed to operate at ultra-low temperatures. The proposed amplifier structure can be easily fabricated on the same chip as the superconducting material, eliminating the need for noisy room temperature amplifiers

1.1. Working principle

Working principle of superconducting nanowire single photon detectors are as follows which is depicted in figure. 1. The output voltage pulse as well as electrical model of SNSPD in the same figure.

1. The initial superconducting state with a bias current I_bias.
2. One photon is incident on the nanowire.
3. A hot spot is formed due to photon absorption.
4. Since the current surrounding the hot spot exceeds the critical current, a part of the nanowire becomes resistive.
5. The hot spot grows as a result of joule heating.
6. With the current dropping and heat dissipated into the substrate, the hot spot vanishes, and the current begins to recover.

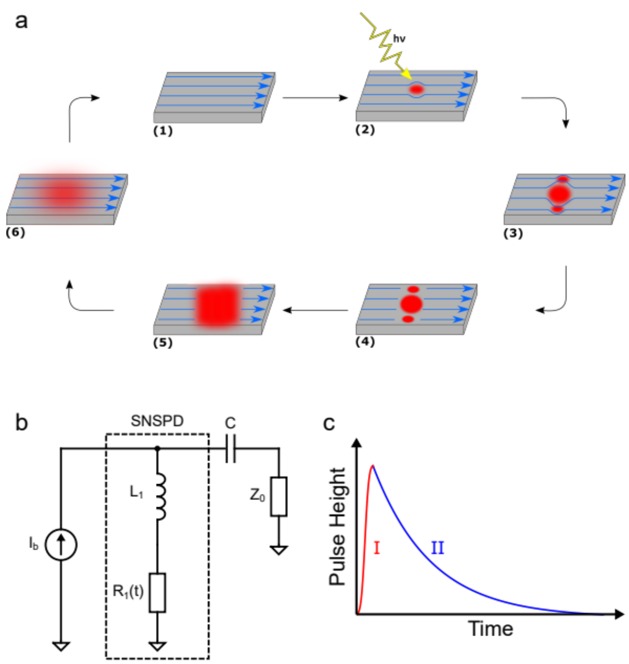

Fig. 1. (a) Detection mechanism of Superconducting Nanowire.[1, 2] (b) Electrical model (c) pulse response

2. Motivation

In traditional setups, an amplifier or equivalent circuitry is essential to enhance the output signal for further measurement. Typically, this amplification process involves either a combination of cryogenic and room-temperature stages or solely relies on room-temperature components. Given the ultra-low operating temperatures of the device, minimizing heat leakage from the system is paramount.

Presently, each detector necessitates its own dedicated amplifier, connected via cables to the system. However, this arrangement introduces heat loss through the cables and lacks scalability, particularly when considering larger detector arrays where amplifiers would be required for each detector. Herein lies the significance of the cryogenic amplifier and the focus of this paper.

By utilizing the pulse from the original setup to trigger the new nanowire stage, a more substantial output pulse can be generated. Theoretically, this concept can be extended into multiple stages, resulting in a significant signal enhancement in a monolithic, scalable manner, as illustrated in Figure 2. Importantly, the required circuitry can be integrated on-chip, facilitating scalability to multiple pixels without encountering heat dissipation issues. Additionally, the fabrication process is considerably simplified as all elements are passive and can be programmatically laid out on the chip, a feat unattainable with conventional semiconductor amplifiers.

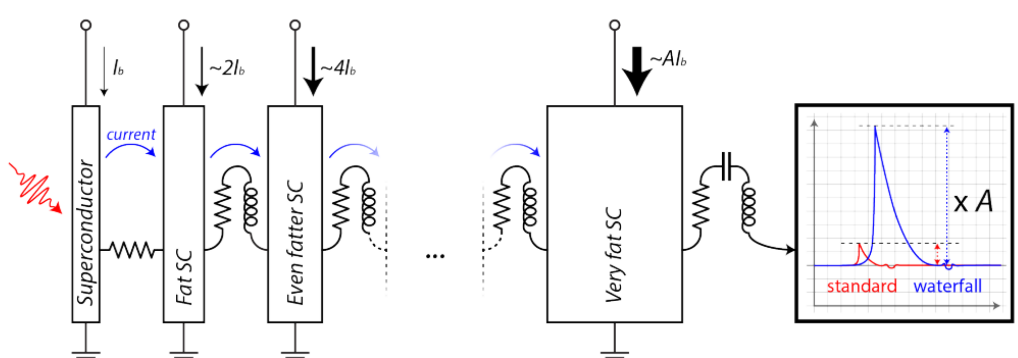

Fig. 2. Schematic representation of the concept of a cryogenic amplifier

3. References

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