Integration of superconducting detectors and CMOS optical modulators for scalable cryogenic readout

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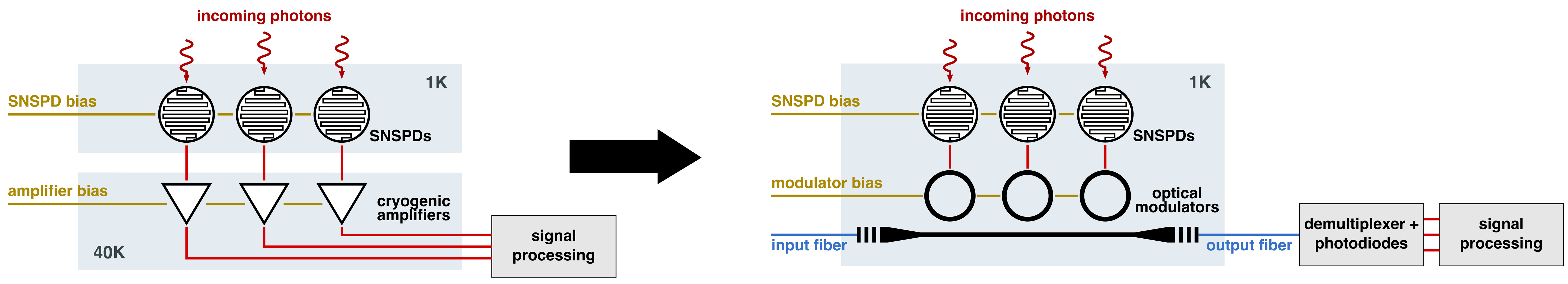
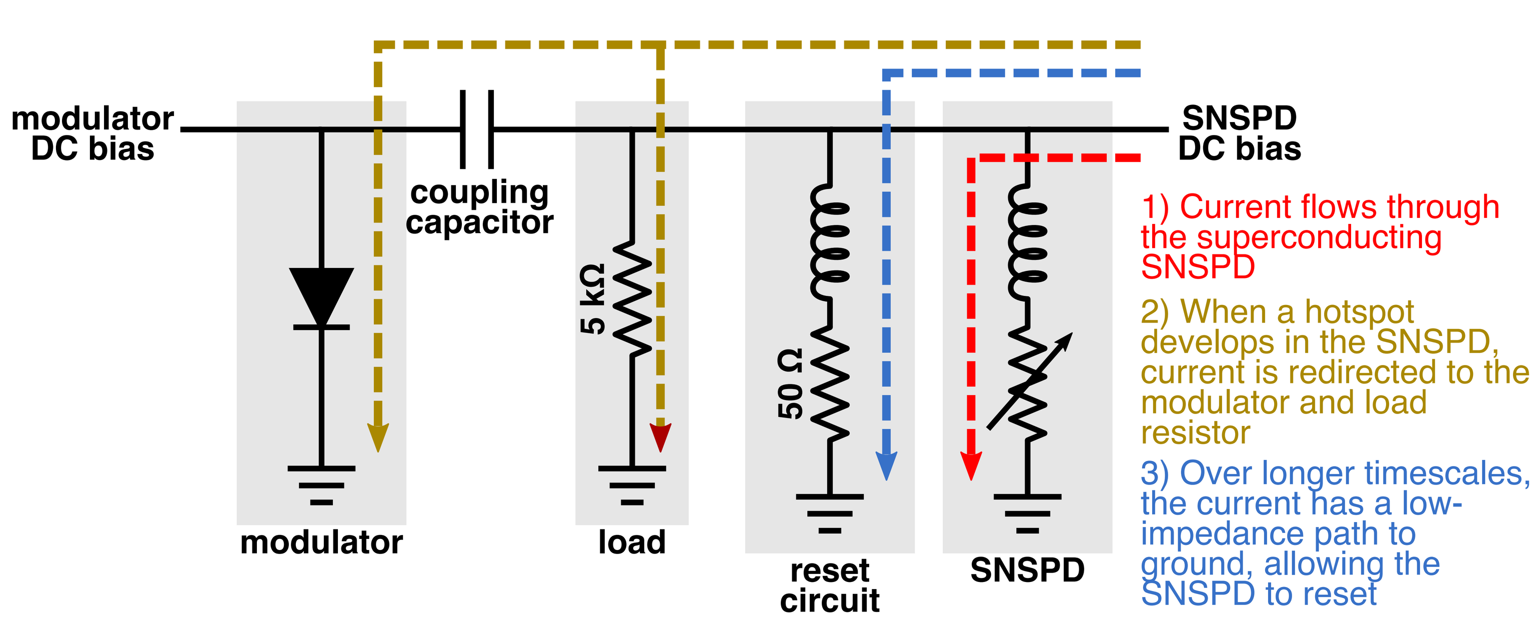
Program: SURP

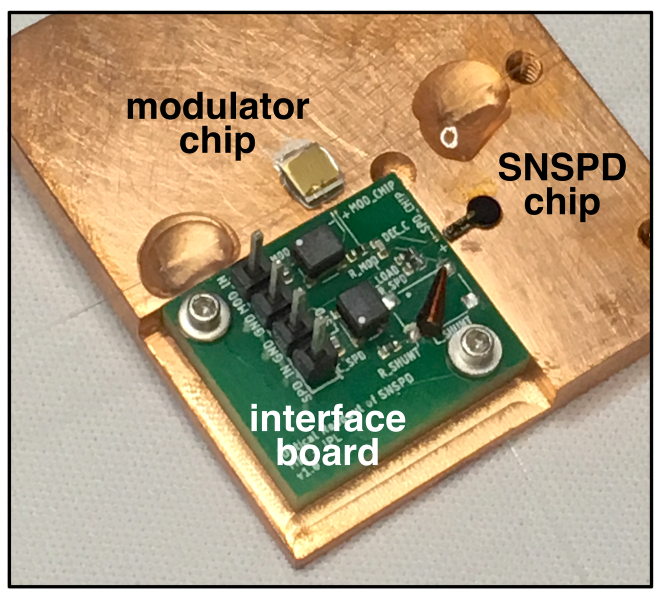
Project Objective: The objective of this project was to demonstrate optical readout of a superconducting nanowire single-photon detector (SNSPD) using an electro-optical modulator.



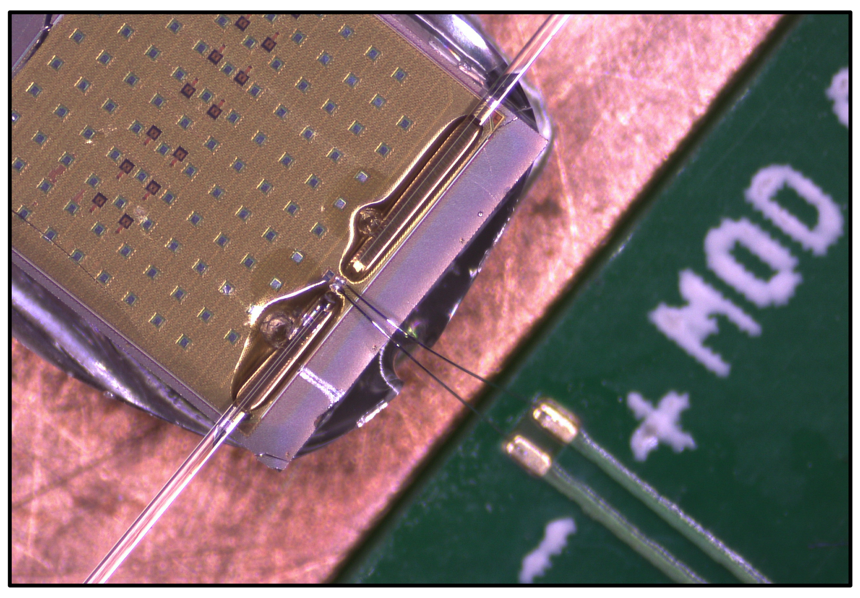
Currently, SNSPD arrays used for laser communication applications are read out using one RF line and amplifier per channel (left). The number of channels is limited by the cryogenic heat load of the high-conductivity RF cables. Cryogenic multiplexing is possible, but most schemes limit the maximum count rate of the array, which is undesirable for laser comm applications. Instead, we propose a scheme where each channel of the array drives an optical modulator and encodes the signal on an optical carrier. By using a laser comb and resonator modulators tuned to different wavelengths, many SNSPD channels can be read out using only one input and one output fiber.

FY18/19 Results:

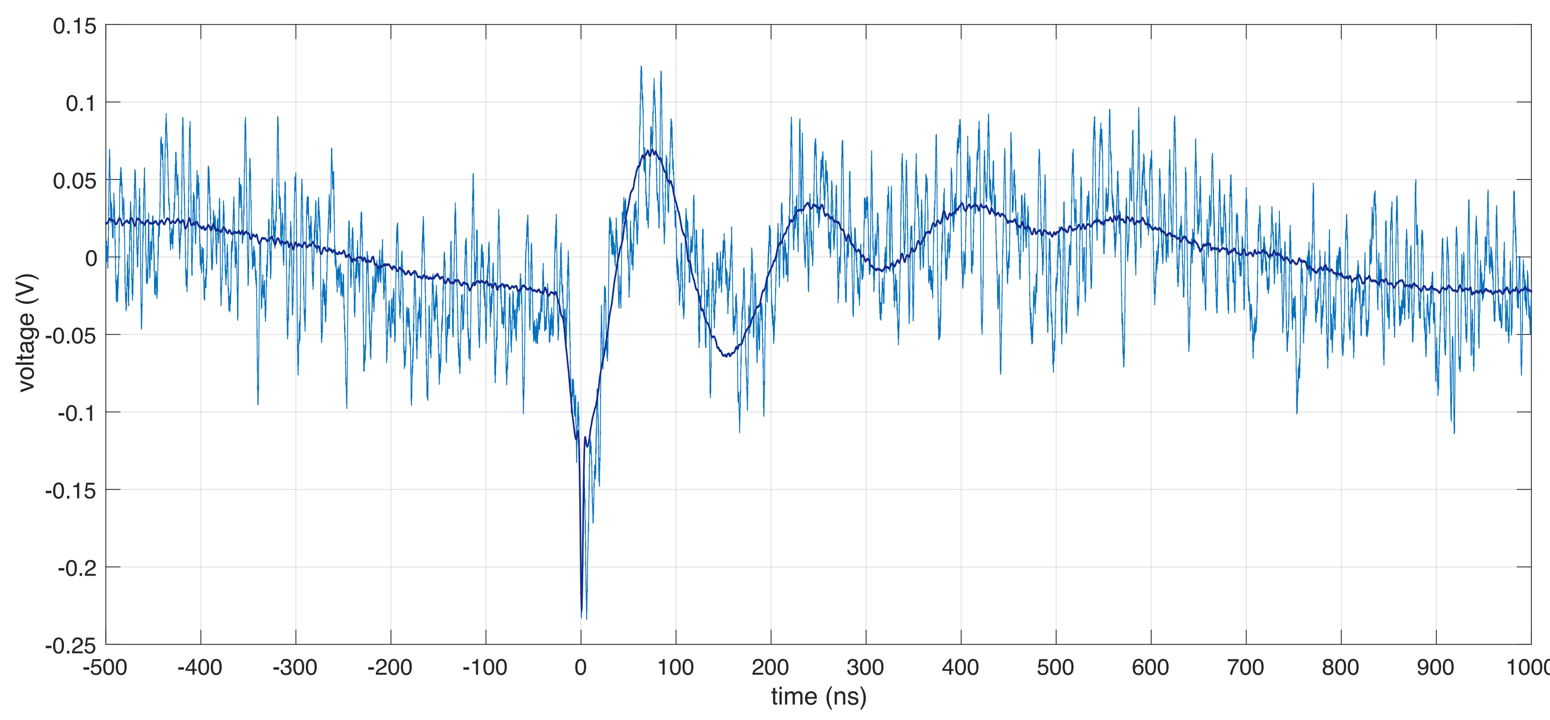




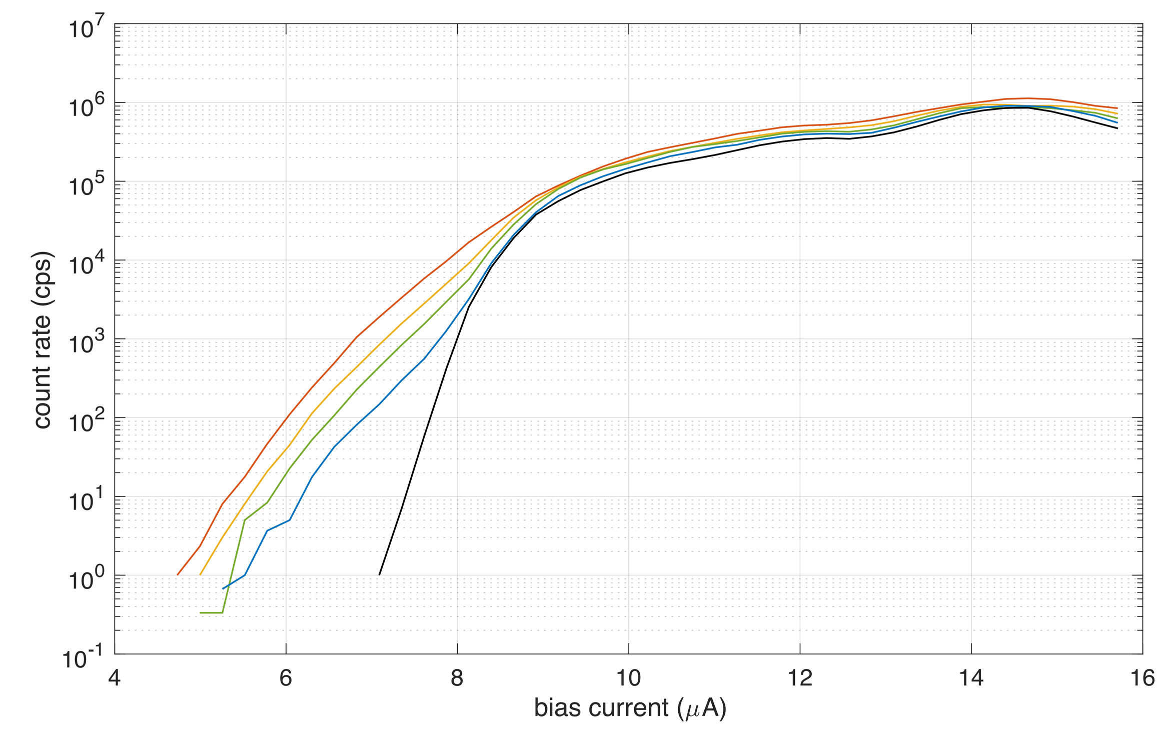
Simplified circuit schematic showing the operational principle of the demonstrated readout scheme. For a proof-of-principle demonstration of optical readout, we combined existing modulator and SNSPD chips using an interface PCB. All components were operated at 3.6 K.



Optical micrograph of the modulator chip showing the input and output optical fibers. Attaching the fibers to the chip in such a way that they would stay aligned with the on-chip grating couplers at low temperatures was a challenge. The total optical losses in our final device were 30 dB, but it is expected that this can be improved to 6 dB.



First demonstration of optical readout of an SNSPD: voltage signal from a photodiode showing the SNSPD's modulation of the optical carrier. Signal-to-noise was limited by optical losses.



Count rate vs. SNSPD bias for different applied optical powers measured with optical readout. The detector is photosensitive in the regime where changing power results in changing count rate. The detector undergoes power-independent relaxation oscillations

Significance of results:

This proof-of-principle demonstration shows the feasibility of optical readout for SNSPDs. Our results also give insight on where progress must be made in order to adapt this architecture for a practical system. For example, decreasing the fiber attachment coupling losses is a straightforward way to increase the signal-to-noise and reduce the heat load of the optical readout system.

With further development, optical readout could be used to combine signals from multiple channels, decreasing the complexity of readout for large SNSPD arrays inside the cryostat. While optical readout of > 100 channels may be possible in the future, in the near term, the readout of ~ 10 channels could be combined with other forms of cryogenic multiplexing to read out arrays of the size and speed required for proposed optical communication projects such as an RF/Optical hybrid DSN terminal.

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