Superconducting Nanowire Single Photon Detector for Coherent Detection of Weak Optical Signals

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Traditionally, photon detectors are operated in a direct detection mode counting incident photons with a known quantum efficiency. This procedure allows one to detect weak sources of radiation but all the information about its frequency is limited by the optical filtering/resonating structures used which are not as precise as would be required for some practical applications. In this work we propose heterodyne receiver based on a photon counting mixer which would combine excellent sensitivity of a photon counting detector and excellent spectral resolution given by the heterodyne technique. At present, Superconducting-Nanowire-Single-Photon-Detectors (SNSPDs) [1] are widely used in a variety of applications providing the best possible combination of the sensitivity and speed. SNSPDs demonstrate lack of drawbacks like high dark count rate or autopulsing, which are common for traditional semiconductor-based photon detectors, such as avalanche photon diodes.

In our study we have investigated SNSPD operated as a photon counting mixer. To fully understand its behavior in such a regime, we have utilized experimental setup based on a couple of distributed feedback lasers irradiating at 1.5 micrometers, one of which is being the Local Oscillator (LO) and the other mimics the test signal [2]. The SNSPD was operated in the current mode and the bias current was slightly below of the critical current. Advantageously, we have found that LO power needed for an optimal mixing is of the order of hundreds of femtowatts to a few picowatts, which is promising for many practical applications, such as receiver matrices [3]. With use of the two lasers, one can observe the voltage pulses produced by the detected photons, and the time distribution of the pulses reproduces the frequency difference between the lasers, forming power response at the intermediate frequency which can be captured by either an oscilloscope (an analysis of the pulse statistics is needed) or by an RF spectrum analyzer. Photon-counting nature of the detector ensures quantum-limited sensitivity with respect to the optical coupling achieved. In addition to the chip SNSPD with normal incidence coupling, we use the detectors with a travelling wave geometry design [4]. In this case a NbN nanowire is placed on the top of a Si3N4 nanophotonic waveguide, thus increasing the efficient interaction length. For this reason it is possible to achieve almost complete absorption of photons and reduce the detector footprint. This reduces the noise of the device together with the expansion of the bandwidth. Integrated device scheme allows us to measure the optical losses with high accuracy. Our approach is fully scalable and, along with a large number of devices integrated on a single chip can be adapted to the mid and far IR ranges where photon-counting measurement may be beneficial as well [5].

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