Superconducting detection for Polarization based QKD - SuperPQ

Alessia Sannino[1,2], Riccardo M. Ienco[3], Ciro Bruscino[2], Chengjun Zhang[2,3], Marco Venturini[4], Maria A. Cutolo[5], Martina Peluso[2], Francesco B. L. Santagiustina[4], Pasquale Ercolano[2], Luca Calderaro[4], Armando Laudati[6], Alberto Micco[5], Diego Scarano[2], Loredana Parlato[2], Giampiero Pepe[2], Giovanni Breglio[2], Giuseppe Vallone[4,7], Daniela Salvoni[1], Simone Capeleto[4]

1. Photon Technology Italy SRL Via G. Gigante 174, 80128 NA (Italy)

2. Università degli studi di Napoli "Federico II", Corso Umberto I 40 - 80138 Napoli,Italy.

3. Qunatech SRL, Via Giacinto Gigante 174, Naples, 80128, Italy

4. ThinkQuantum S.R.L Via della Tecnica, 85. I-36030 Sarcedo (VI) –Ital

5 CeRICT Scrl, Benevento, Italy

6. Optosmart Srl, Napoli, Italia

7. Università degli Studi di Padova, Via G. Gradenigo 6/b 35131 Padova, Italy

Abstract: The SuperPQ project developed polarization-independent superconducting detectors for quantum cryptography. Fractal-geometry microstrips and optimized filters achieved 56 dB attenuation and 50 kbps key rates, overcoming a critical technological barrier for secure quantum networks.

Quantum Key Distribution (QKD) represents a strategic frontier for communication security, as evidenced by ongoing metropolitan tests and the development of dedicated infrastructures. However, the widespread integration of this technology—although already available in commercial systems based on the BB84 protocol—is hindered by purely technological limitations. The Superconducting detection for Polarization based QKD - SuperPQ project, funded by the PNRR as part of the NQSTI-Spoke 8 cascade call, addresses one of these critical issues: the polarization dependence of Superconducting Nanowire Single-Photon Detectors (SNSPDs) [1]. While these sensors enhance the range and speed of key exchanges, their sensitivity to the polarization state of light introduces a vulnerability for QKD protocols that use this property to encode information.

The project pursued a dual objective: to thoroughly understand the impact of this phenomenon on system security, and simultaneously, to develop effective countermeasures to create "polarization-independent" detectors. The research pathway began with an in-depth literature review and simulations, progressing to the design and fabrication of novel sensor architectures and optical filters. Experimental activities involved characterizing both commercial devices and next-generation prototypes, fabricated using innovative materials such as MoSi and NbRe. The results achieved have met all key project milestones. Measurements quantified the high polarization sensitivity of traditional SNSPDs, in contrast to the more stable performance of devices coupled with multimode fibers. The most significant outcome was the realization of a superconducting microstrip single-photon detector (SMSPD) prototype with a fractal geometry, which demonstrated substantial polarization independence, thereby validating one of the most promising design strategies. In order to reduce the Dark Count Rate (therefore DCR), a wavelength-selective optical filter has also been developed directly on the tip of the fiber. Such filter has been realized by using nanometer multilayer electron-beam evaporation technology, allows the detector to be illuminated with only the signal components. On the application front, the integration of commercial detectors into a QKD testbed and the optimization of post-processing algorithms pushed system performance to 56 dB of channel attenuation, with secret key generation rates (SKR) reaching 50 kbps in the low-loss regime. These results not only confirm simulation models but also chart a concrete path for the use of next-generation superconducting detectors in future QKD systems, making a substantial contribution to the expansion and optimization of secure quantum networks.

References

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