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SINGLE QUANTUM

Short Term Scientific Mission (STSM) Report for COST Action CA15127 RECODIS

IMPLEMENTING SUPERCONDUCTING NANOWIRE SINGLE PHOTON DETECTOR (SNSPD) IN TERMS OF IMPROVED FSO SYSTEM RELIABILITY

1 STSM Details

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STSM period:	From 2017-04-01 to 2017-04-09 (9 days)
Working group:	WG2 - Weather-based disruptions

2 Purpose of STSM

The influence of free space optical (FSO) systems increase more and more in the last decade. In comparison with the other wireless communication technologies they have numerous advantages including enormous bandwidth or data rates respectively, high-collimated optical beam, and no wiretapping problems. All this advantages are the reason that wireless optical systems are implemented in various scenarios and applications. However the main drawback of FSO technology is the very high dependence on atmospheric conditions which induce very high attenuation. This includes mainly fog, clouds and turbulence which are the main problems. Although FSO systems are normally used for terrestrial last mile access, they are also implemented in deep space communications. Generally, in this extremely long distance links the attenuation level is very high or the received signal is equivalent to single photons. In other words in deep space communications a photon-counting detector which can respond on signal photon incidence is necessary. Regarding the discussion till now, in the current STSM a superconducting nanowire single photon detector (SNSPD) of Single Quantum Company is truly investigates as a possible solution for reliable space communications. Based on its implementation in different scenarios, the influence of various atmospheric effects such as fog and clouds events can be significantly mitigated. The main points of the current research in the frame of COST action: CA15127 RECODIS, WG2 are:

- Possibility to have a good overview of the technology behind the SNSPD detector
- Participating in SNSPD laboratory measurements and more specifically photon detection experiments. This includes mainly its application in deep space communications where the enormous distance and troposphere influence disrupt in great amounts the transmitted signal.
- Acquiring an ability to operate with the specially developed SNSPD's GUI and also to accomplish the proper device settings.
- Receiving enough skills for proper system installation which is from crucial importance for the current task.
- Coping with the correlation between the different system channel output ports, which are up to eight.

In conclusion the current completed STSM in frame this COST action RECODIS is very narrow related to Working Group 2, which main objective is to increase the reliability of end to end communication links in the presence of different atmospheric distortion problems. The proposed SNSPD detector is one very effective way for completion of this objective.

3 Description of the work carried out during STSM

In the frame of the current STSM I have a scientific research stay in Single Quantum Company. My stay includes different activities mainly related to the following:

- Participation in a presentation given by Dr. Sander Dorenbos and Dr. Jessie Qin-Dregely in terms of SNSPD operation and applications
- Daily discussions with Dr. Sander Dorenbos and Dr. Jessie Qin-Dregely related to the implementation of the detector in my future deep space communication laboratory experiments
- Accomplishing analytical studies in terms of detector operation
- Getting familiar and conducting laboratory experiments in the Single Quantum situated in Technical University Delft, Nederland.

In the end of my research stay in Single Quantum Company I held a presentation over the main activities of Optikom group of TU Graz and my PhD research in European Space Agency Center ESTEC, Noordwijk, Nederland. One of the major points during my talk was related to the laboratory measurements with the SNSPD detector within COST RECODIS WG2. It was explained that the current device is from significant importance for the FSO communications in terms of increasing system reliability and availability.

Wireless optical communication is faced by different issues. The most severe ones are the atmospheric perturbation effects which can cause in some cases also a link interruption and data losses respectively. Basically deep space FSO links are passing through all troposphere where all different weather effects are presented. However the main atmospheric influences responsible for the attenuation and blockage of the FSO systems are fog, clouds and turbulence. The particle size in case of fog and clouds are comparable with the optical wavelength which leads to attenuation due to Mie scattering [1]. Clouds produce easily atmospheric attenuation exceeding 15 dB up to hundreds of dB/km, which could block the optical signal completely. They also introduce temporal dispersion, causing pulse spreading, which limits the bandwidth and makes the effect of clouds even more severe than fog. In general fog can be divided in two types, namely maritime and continental fog which differ in the amount of the imposed attenuation. The maritime fog is very similar to clouds and consequently can cause attenuation hundreds of dB/km. Furthermore this event is very unstable with fluctuations of hundreds of dB/km for one second period. In case of continental fog the attenuation is significantly lower with a peak around 100 dB/km (measurements - Graz Austria). In addition the fluctuations of the attenuation are small or in other words the continental fog is considerably stable [2].

One effective solution to mitigate atmospheric influences is implementation of proper detector in the receiver side. In case of deep space FSO communications, to overcome the enormous distances and atmospheric effects we need a very high sensitivity detector. In general, one good and cheaper choice can be Geiger mode Avalanche Photo Diode (APD). This detector is biased close to the threshold, so a single photon could trigger an avalanche or in other words big enough impulse. However the performance of the APD is not satisfactory enough in terms its internal parameters such as deadtime, dark count rate and quantum efficiency. In other words the Signal to Noise Ratio (SNR) and the data rates cannot be high enough for the most of the applications. To overcome these issues the superconducting nanowire single photon detector of Single Quantum Company, which is far more effective, will be used.

Although it is not completely proved it is scientifically accepted that the energy of photons break the cooper pairs which leads to a fixed resistance in part of the nanowire. In other words a detection of single photon event happens [3]. Based on this concept the operation of the SNSPD is explained in the paper [4].

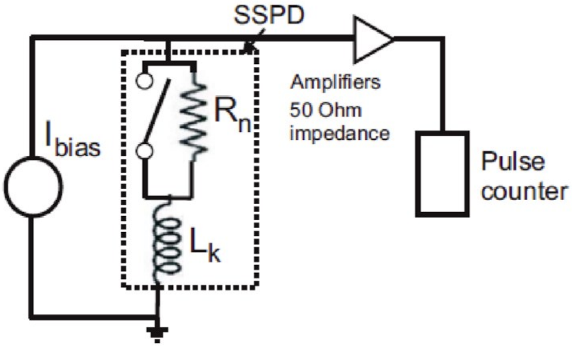

Fig. 1 Architecture of the Single Quantum detector [4].

According to Fig. 1, SNSPD device can be described in theory as a switch. When the switch is closed, the detector woks in superconducting mode. This is allowed by the fact that a closed cycle cryostat system is used, which cools down the device near to the absolute zero. However when a single photon is received the superconductivity is destroyed. In other words, part of the detector becomes resistive which allows the current to flows through the amplifier and to give a voltage pulse. The SNSPD device is biased with a direct current I_b which is chosen in terms of a couple of factors. Firstly, the I_b has to be very near to the critical current I_c but not above its value. In case, the value of the I_c is passed the nanowire´s superconductivity will be broken. The second one is a tradeoff between quantum efficiency and dark count rate. In other words if the direct current is nearly equal to the critical one the quantum efficiency will be maximum. However the dark noise will be also maximum which will decrease significantly the SNR.

Consequently the SNSPD device has to be preliminary calibrated to the developed system configuration and desired final parameters respectively [4].

Based on the above explained concept,t the SNSPD detector can be used for different FSO deep space communication scenarios where atmospheric effects are one of the main issues. In other words this detector could be a key component for increasing the reliability and availability of FSO system, which is also the main task of WG2 in COST RECODIS. To prove this idea, in the next section a measurement showing the operation of SNSPD in laboratory conditions is discussed. In addition also the calibration process is properly accomplished.

4 Description of the main results obtained

In the current section the results obtained during the stay in Single Quantum Company are shown. The architecture of the laboratory setup applying SNSPD device is presented in Fig. 2.

Fig. 2 Architecture of the applied laboratory setup

The measurement setup in Fig. 2 includes the following three main components:

- Tunable laser which operates in near infrared spectrum, namely 787 nm wavelength
- Tunable attenuator which can attenuate the optical laser power up to levels of single photons (in this case till -60 dBm)
- SNSPD device with 8th different separated channels. In case of this measurement, only the 1st one is used

Once the above setup is built, the SNSPD can be calibrated and tested. The output laser power is -10 dBm which is too high value for a single photon detection and will lead to detector saturation. In other words an optical attenuator which decreases the optical power level up to -60 dBm is applied. After this procedure is accomplished the optical fiber is coupled on the 1st channel port of the detector. The measurement results are shown below.

In Fig. 3 the threshold critical currents for the eight channels is shown. In this case the input signal is not considered and only the internal SNSPD electrical circuit is tested.

Fig. 3 SNSPD´s monitored voltage versus biased current graph

According to Fig.3 when the biased current (I_b) is enough increased, there is one point when the superconductivity of the detector is already broken. In other words after this point the detected voltage levels increase and single photons cannot be detected anymore. As we can see the critical current (I_c) for the first channel is 17,2 uA.

After we have already known the critical current, we can test the system with the already discussed setup. In Fig. 4 is presented the number of absorbed photons per second versus the biased current for each of the eight channels. We are interested only in the first channel which is coupled with the explained setup. The other seven channels are closed and consequently only the dark count rate noise is visible. In terms of a faster performance the X axis is restricted up to 20 uA which leads to possibility to see only six out of eight channels.

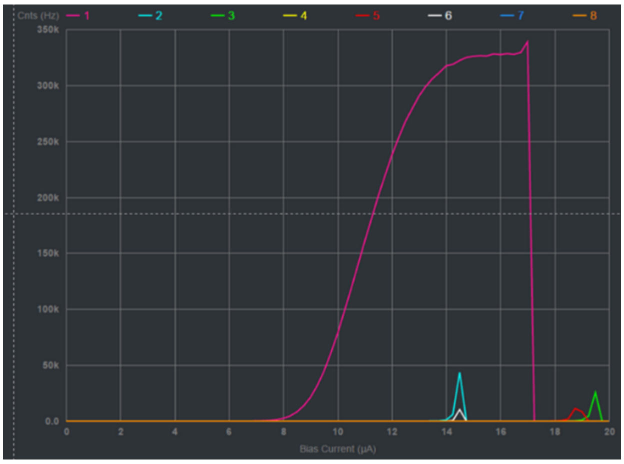

Fig. 4 SNSPD´s detected photons per second versus biased current graph

Regarding the 1st channel in Fig. 4 it is clear that when the biased current is increased, the possibility to absorbed more photons per second is also higher. However when it is reached the already discussed critical current (which is 17,2 uA), it is not anymore possible single photon events to be detected. Very near to this threshold is the maximum allowed number of absorbed photons, which for the current detector is around 340k photons/sec. Based on this value the calculated efficiency is equal to around 80% which is extremely satisfactory result and one proof for the reliability of the detector. To calibrate properly SNSPD device here also the dark count rate of the 1st channel is measured. The results are shown in Fig. 5.

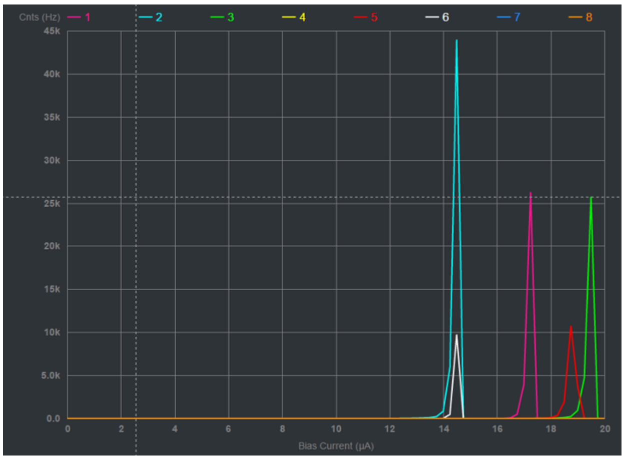

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Fig. 5 SNSPD´s dark count rate versus biased current graph

According to Fig. 5, the maximum dark count rate it is very near to the critical current and it is equal to 25k photon/sec. In other words, to obtain a satisfactory SNR together with a high enough efficiency, the biased current has to be very close but not equal to the maximum allowed photons per second value. Consequently for our laboratory measurement the optimal value for the biased current is taken to be 16 uA.

5 Future collaboration and foreseen publications

During my STSM in frame of COST RECODIS, I obtained important knowledge and also I participated in measurements with the SNSPD device. This single photon detector is of crucial importance for my future research. Based on it, the reliability of deep space FSO communication links can be significantly increased in the present of various deteriorative atmospheric effects. In other words, I will continue the narrow collaboration with Single Quantum Company initiated in WG2. Consequently the deep space communications in terms high reliability will be further examined. The future plans also include a publication in an appropriate conference and journal.

References

[1] T. Plank, E. Leitgeb and M. Loeschnigg, “Recent developments on free space optical links and wavelength analysis,” IEEE, Space Optical Systems and Applications, May 2011

[2] E. Leitgeb, S. Sheikh Muhammad, B. Flecker, C. Chlestil, M. Gebhart, and T. Javornik, “The influence of dense fog on optical wireless systems, analysed by measurements in Graz for improving the link-reliability,” in Proceedings of 2006 ICTON, Nottingham, United Kingdom, 18th -22th of June 2006

[3] S. N. Dorenbos, P. Forn-Díaz, T. Fuse, A. H. Verbruggen, T. Zijlstra and et al., “Low gap superconducting single photon detectors for infrared sensitivity”, Applied Physics Letters 98, 251102, 2011

[4] S. N. Dorenbos, E. M. Reiger, U. Perinetti, V. Zwiller, T. Zijlstra and et al., “Low noise superconducting single photon detectors on silicon”, Applied Physics Letters 93, 131101, 2008