Application Note

Using an SNSPD and an electro-optical modulator to sample fast RF signals

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There are two types of oscilloscopes to measure radio frequency (RF) signals: Real-time and sampling oscilloscopes. Typically, sampling oscilloscopes provide more electrical bandwidth, but they need a repetitive signal to analyze. Often sampling scopes are used to analyze optical signals. In this application note, we showcase how a superconducting single-photon detector (SNSPD) can be used to analyze low-power optical signals together with a time tagger. In the present work, we characterize a 200 ps wide pulse from a fast pulse generator.

Working Principle

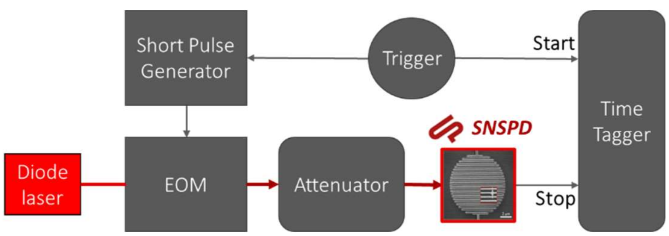

Figure. 1: Optical random sampling Measurement setup.

The measurement principle is based on optical random sampling, namely a start-stop correlation measurement as depicted in *Figure 1*. A trigger signal enables the pulse generator to produce a test-pulse and triggers the start port on the time tagger. The test-pulse is converted into a light modulation in an integrated 10 GHz - 10 Gbit/s iXblue electro-optical modulator whose role is to encode the RF trace into the incoming light emitted from a laser diode. The output light is then attenuated to the single-photon level with about 300 KCts/s. This optical signal is detected by a SNSPD whose electrical pulses trigger the stop-channel on the time tagger. The event timestamps are then acquired on each channel and later processed in software. The higher the signal amplitude the more correlations will be recorded.

Correlation Measurement – Bandwidth vs Jitter

The key concept in single-photon random sampling is that the effective bandwidth is not limited by the analog bandwidth of the detection system but by its timing jitter. The 3dB point of the effective measurement bandwidth reads:

$$BW_{3d} = 0.44/\,Jitter_{total}$$

The jitter of an SNSPD can be as low as 7.7 ps [1] together with the best time tagger [2] would lead to a total jitter of:

$$Jitter_{tot} = \sqrt{Jitter\,^2_{SNSPD} + Jitter\,^2_{Time-Tagger}}$$

$$Jitter_{tot} = \sqrt{7.7ps^2 + 3.0ps^2}$$

And an effective bandwidth of:

$$BW_{3dB} = 0.44/\,8.3\,ps = 53\,GHz$$

Using an SNSDP with jitter of 17.5 ps along with a *PicoHarp 300* time tagger from PicoQuant yields to a total jitter of:

$$Jitter_{tot} = \sqrt{17.5ps^2 + 20.0ps^2}$$

Resulting in an effective bandwidth of ***16.5*** GHz. It must be noted that this experiment is limited by the 10 GHz EOM's modulation bandwidth. However, commercially available EOMs can reach up to several tens of GHz. *Figure 2* Compares the test-pulse measured with either an oscilloscope (RTO2014) with 4 GHz bandwidth (Left) with the outcome of the optical sampling (Right) where the correlations are shown in a density plot in red and the weighted average density in blue. The role of the density plot is to count the occurrence probability, namely how many times the correlations per time bin fall in a specified interval.

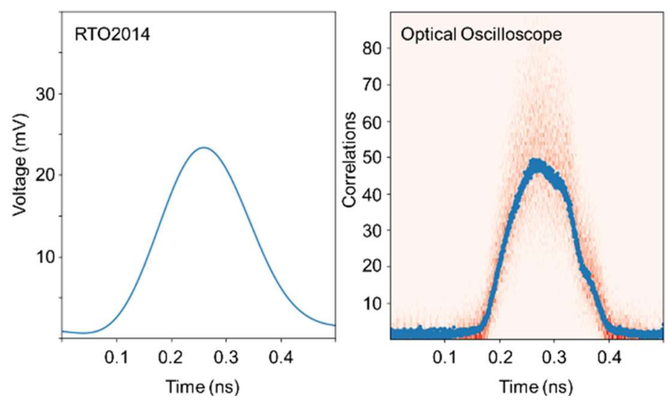

Figure. 2: (Left) Trace measured with RTO2014 (4GHz Bandwidth). (Right) Density plot using *PicoHarp 300* shown with red pixels. The blue dotted line is the weighted average over the correlations per time bin.

Conclusion

This proof-of-principle optical scope demonstrates the possibility to capture high frequency signals that are either electrical or optical. Since this technique relies on the detection of single photons, the use of SNSPDs is an inevitable choice to reach very high measurement bandwidth.

References

[1] *ACS Photonics* **2020** *7* (7), 1780-1787
[2] https://www.becker-hickl.com/products/spc-150nxx/

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