Single-photon random sampling of optical signals

Single-photon random sampling enables easy and precise measurements of optical signals – up to the THz regime

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Single-photon counting has found broad applications within quantum technologies, such as quantum sensing, quantum information and quantum communication. Recently it was proposed that low jitter single-photon detectors could be used to realize optical random sampling scopes with a bandwidth well beyond 100 GHz, a range not accessible with existing measurement instrumentation. This technique is suitable to support research on mode locked lasers and next generation electro-optical devices such as EOMs and VCSELs. In the Swabian Instruments demo session paper, we showcase a proof of principle measurement and characterize commercial SFP+ modules using both Single-Photon Avalanche Detectors (SPADs) and Superconducting Nanowire Single-Photon Detectors (SNSPDs). With the jitter of current SNSPDs reaching a few picoseconds, the method promises a measurement bandwidth well beyond 100 GHz.

MEASUREMENT SETUP

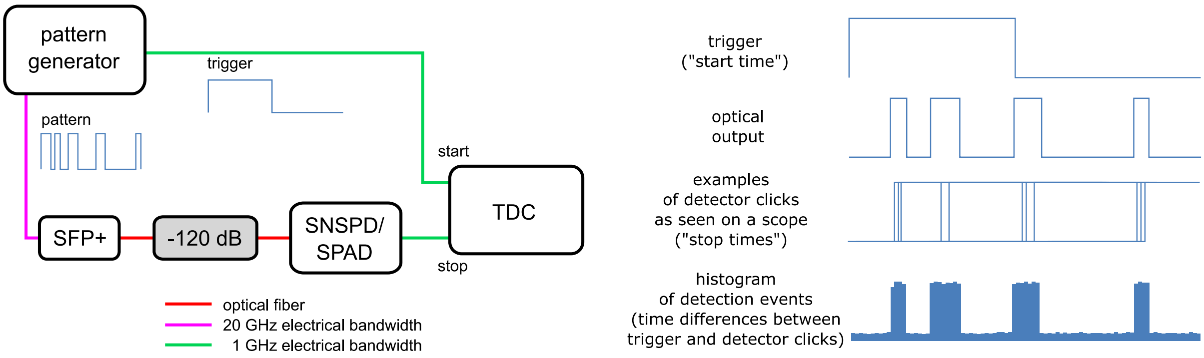

Figure 1. Measurement setup and single-photon random sampling scheme.

Figure 1 illustrates a measurement setup that characterizes the modulation response and eye diagram of an SFP+ module using single-photon random sampling. The optical output of the SFP+ module is attenuated by about 100 dB. A suitable attenuator is an air gap of about 20 cm. The remaining optical power, about 100 fW is directed into a single-photon detector. Single-photon avalanche detectors (SPADs) and superconducting nanowire single-photon detectors (SNSPDs) are suitable for this purpose. The attenuated power results in an average single-photon rate of about 1 M counts/s. This small rate ensures that the average time between two photon detection events is much larger than the detector dead time (typically about 50 ns) such that the single-photon detectors are operated in the linear regime well below saturation.

The setup is driven by a digital pattern generator that delivers two synchronous outputs: one output is a 10 Gbit/s pattern that is applied to the SFP+ module. The second output provides one trigger pulse for each pattern. The triggers are captured with a Swabian Instruments Time Tagger Ultra, which serves as a time-to-digital converter (TDC) and are interpreted as “start” clicks. The electrical output pulses from the single-photon detector are captured on a second channel of the Time Tagger Ultra TDC and are interpreted as “stop” clicks. The TDC measures the time differences between ”start” and ”stop” events and accumulates them in a histogram, thereby providing a random sampled representation of the optical intensity. The optical pattern and the trigger pulses are generated repeatedly with a rate of about 10 MHz. Note that with the given photon count rates, on average less than one photon is detected per cycle.

RESULTS

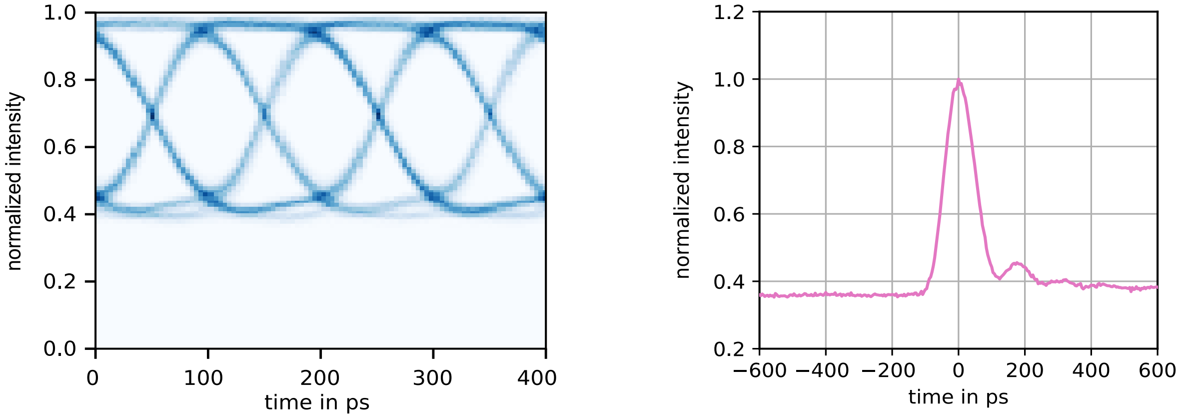

Figure 2. Example measurements: eye diagram and pulse response of an SFP+ module.

Figure 2 shows two representative measurement results. The left panel shows the pulse response of the SFP+ module measured with an SNSPD. The right panel shows the eye diagram of the SFP+ module measured with a SPAD. This proof of concept measurement shows that single-photon random sampling enables precise measurements of fast optical signals.

OUTLOOK

How far can this method be pushed? To understand how powerful the technique is, it is instructive to consider the analog bandwidth of the various signal paths of the system (see left panel of Fig. 1). The electrical signal that drives the SFP+ module requires about 20 GHz analog bandwidth. By contrast, the trigger pulses that are output by the single-photon detectors cover an analog bandwidth of only a few GHz. Thus, simple RG316 SMA cables or even BNC cables and input discriminators with moderate bandwidth are enough to deliver the detector signals to the TDC. This aspect is of prime importance: with single-photon random sampling, the measurement bandwidth is not determined by the analog bandwidth of the detector and TDC. It is rather determined by the jitter of the single-photon detector and TDC. This enables us to conceive an optical sampling scope with a bandwidth that could reach into the THz regime without the need of handling high frequency electric signals. Specifically, SNSPDs with 2.7 ps FWHM jitter have recently been demonstrated [1]. By the following expression

$$BW_{3dB} = 2\ln 2/(\pi \cdot FWHM) = 0.44/FWHM$$

such low jitter translates into an effective measurement bandwidth of 160 GHz. And this is not the limit. Single-photon random sampling is clearly capable of pushing the limits in high bandwidth optical signal measurements.

CONTACT US!

Are you interested in this technology? Use your opportunity to get involved in our early development stage and get in touch with us!

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[1] B. A. Korzh et al. "Demonstrating sub-3 ps temporal resolution in a superconducting nanowire single-photon detector," arXiv:1804.06839 (2018).