Low-noise single-photon dectector for long-distance free-space quantum communication

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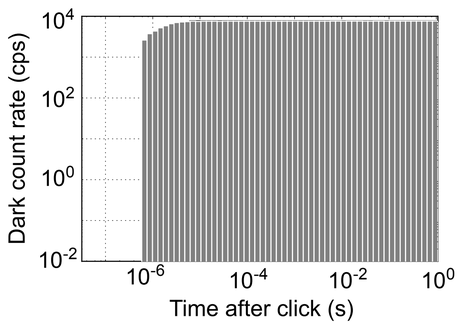
Afterpulsing

$$f(t) = D + \sum_{i=1}^{n} (A_i \cdot e^{-\frac{t}{t_i}})$$

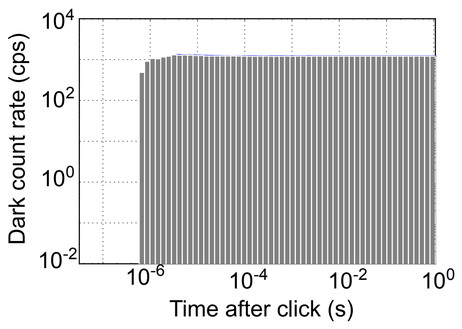
where *D* is dark count rate

0˚C, 14 V above breakdown



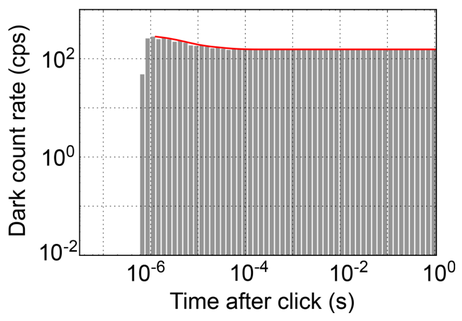
D=7603 cps
P_{aft}=0 %

−20˚C



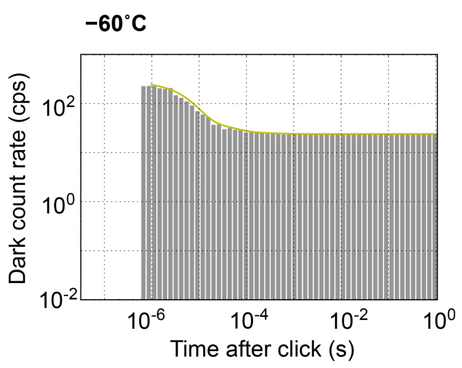
A_1=128
t_1=1.05·10⁻⁵ s
D=1213 cps
P_{aft}=0.12%

−40˚C



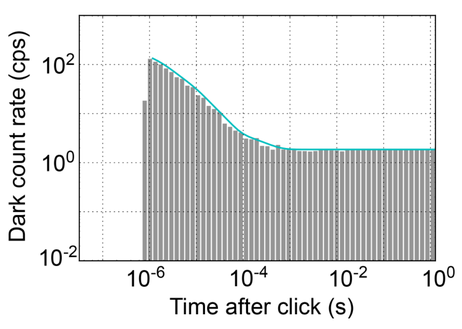
A_1=119
t_1=4.18·10⁻⁶ s
A_2=40.59
t_2=2.77·10⁻⁵ s
D=155 cps
P_{aft}=0.16%

−60˚C



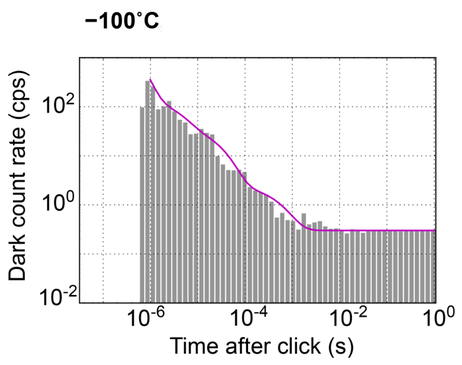
A_1=234
t_1=5.37·10⁻⁶ s
A_2=19.39
t_2=4.32·10⁻⁵ s
A_3=2.34
t_3=3.73·10⁻⁴ s
D=24 cps
P_{aft}=0.3%

−80˚C



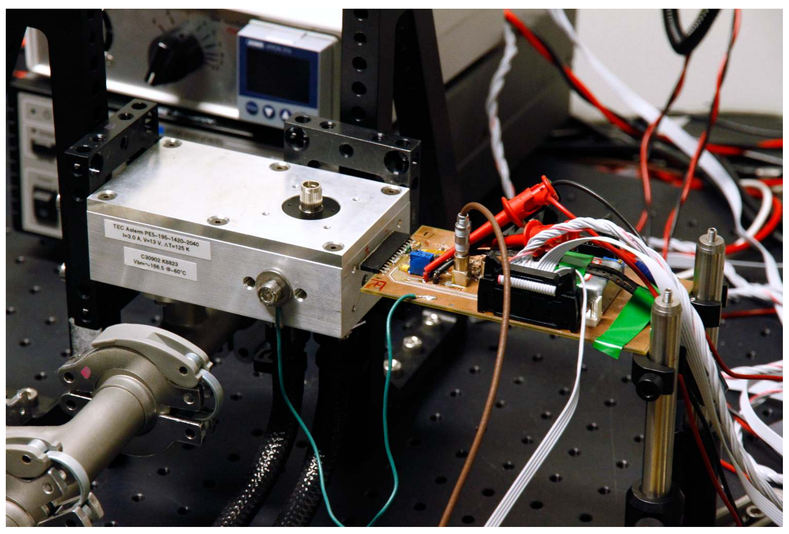
A_1=133
t_1=1.37·10⁻⁶ s
A_2=61
t_2=6.13·10⁻⁶ s
A_3=23
t_3=2.44·10⁻⁵ s
A_4=2.59
t_4=2.2·10⁻⁴ s
D=1.86 cps
P_{aft}=0.13%

−100˚C



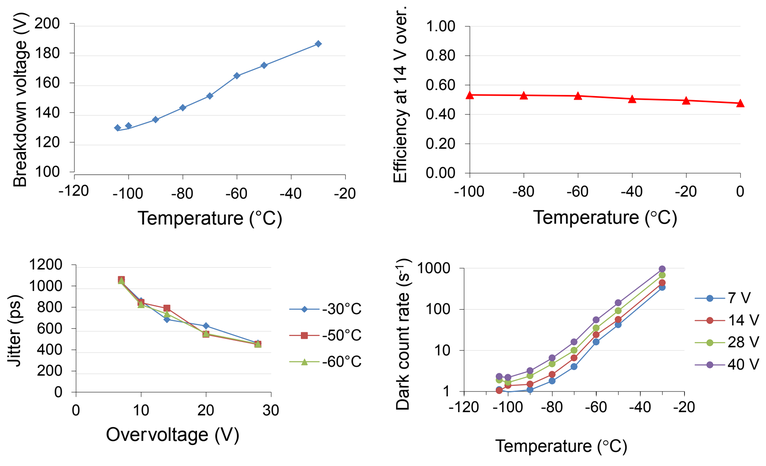
A1=3447
t_1=3.62·10⁻⁷ s
A_2=123.5
t_2=3.38·10⁻⁶ s
A_3=37.87
t_3=2.75·10⁻⁵ s
A_4=2.31
t_4=4.83·10⁻⁴ s
D=0.3 cps
P_{aft}=0.43%

Detector design



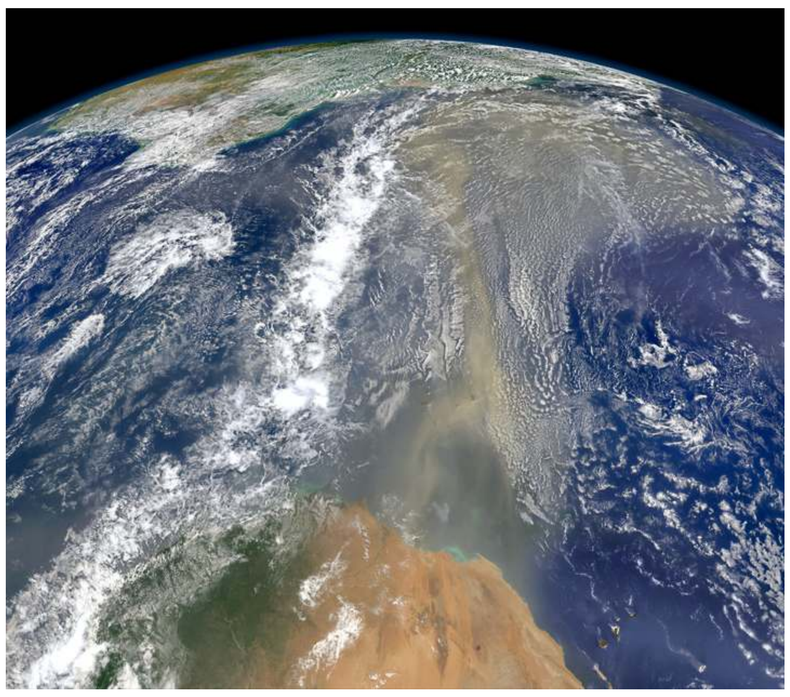
5-stage TEC, 30 W electrical (Osterm PE5-195-1420-2040)
Temperature range: +25..-105 ˚C with water cooling
APD: Excelitas C30902SH
Vacuum: <10^{-3} Torr
Passive quenching circuit

Detector characteristics



Application example

X.-S. Ma *et al.,* Quantum teleportation over 143 kilometres using active feed-forward, Nature **489**, 269 (2012).



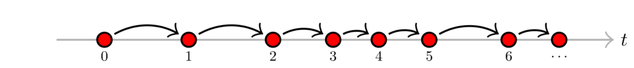
Sand wind over Atlantic from Sahara desert on June 24, 2014 (image from NPP Suomi VIIRS satellite).

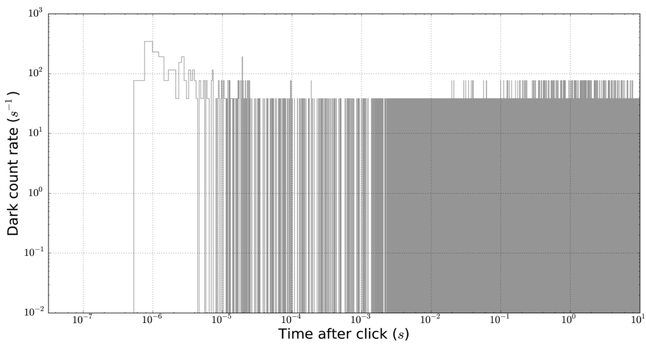
Improved afterpulsing analysis

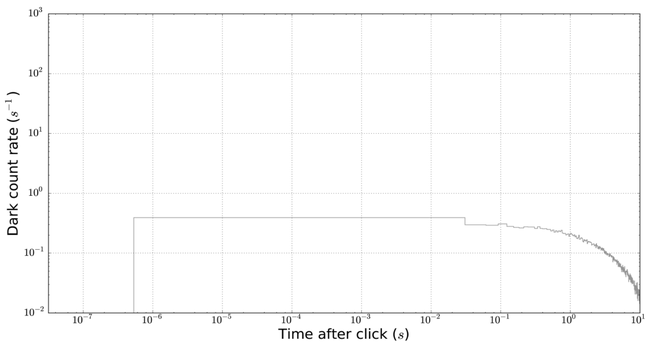
Diode: Excelitas C30902SH, temperature: −100 ˚C, duration of experiment: 5.5 days, total counts:114109

Algorithm autocorrelation (standard processing)

```
bins = [equal sized bins up to 1.0 sec]
difflist = [list of consecutive differences]
for i = 0 to last :
    difflist[i] = data[i+1] - data[i]
end
plot histogram(difflist, bins, normalized, log-log)
```

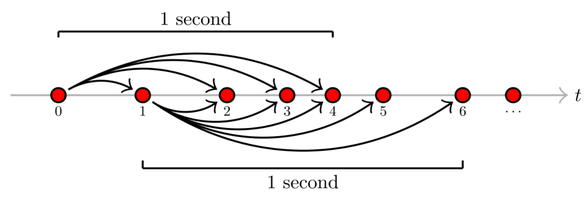


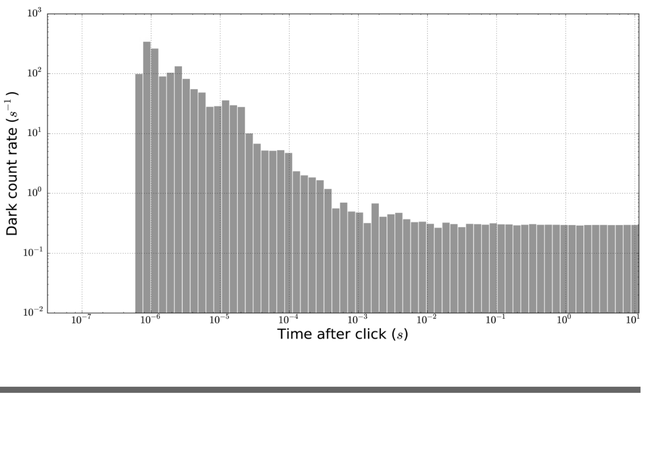




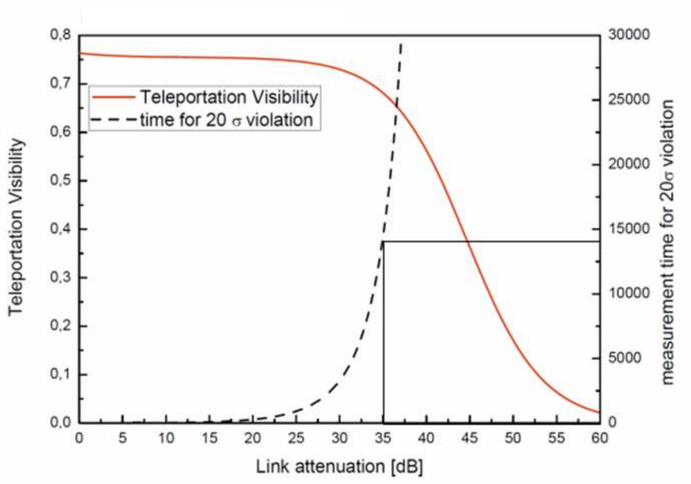
Algorithm improved processing

```
bins = [exponentially growing bins up to 1.0 sec]
diffsperbin = [number of diffs that fall in each bin]
for i = 0 to last :
    stop = index of last data point ≤ 1.0 sec from data[i]
    for j = 1 to stop :
        diff = data[i+j] - data[i]
        binnum = bin number that diff falls in
        diffsperbin[binnum]++
    end
end
plot bar(diffsperbin, bins, normalized, log-log)
```

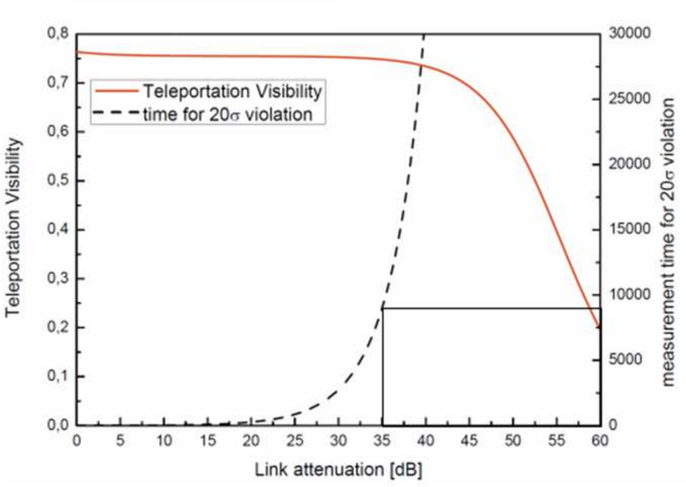




Application simulation



dark count rate 600 cps 4 h per data point



dark count rate 50 cps 2.5 h per data point

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