Counting Photons Using a Nanonetwork of Superconducting Wires

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Abstract. We show how the parallel connection of photo-sensitive superconducting nanowires can be used to count the number of photons in an optical pulse, down to the single-photon level. Using this principle we demonstrate photon-number resolving detectors with unprecedented sensitivity and speed at telecommunication wavelengths.

A superconducting nanowire biased close to the critical current can be used as a single-photon detector [1]: As a photon is absorbed, a nanoscale hot-spot is formed, producing a resistive transition across the wire, which is detected as a voltage pulse in the external circuit. However, a single wire (usually patterned into a meander shape to increase the active area) has a response nearly independent of the number of incident photons, as the resistance produced by the absorption of a single photon is sufficient to divert all the current to the external circuit. We have recently proposed [2] a novel detector architecture, the "Parallel Nanowire Detector" (PND), which provides an output electrical pulse whose amplitude is proportional to the incident photon number. The basic structure of the PND is the parallel connection of N superconducting nanowires, each connected in series to a resistor R_0 (Fig. 1). In this parallel configuration, the currents from different wires can sum up on the external load, producing an output voltage pulse proportional to the number of photons.

PNDs were fabricated on ultrathin NbN films (4nm) on MgO and R-plane sapphire using electron beam lithography (EBL) and reactive ion etching. Detector size ranges from 5x5 μm^2 to 10x10 μm^2 with the number of parallel branches varying from 4 to 14. The nanowires are 100 to 120 nm wide and the fill factor of the meander is 40 to 60%.

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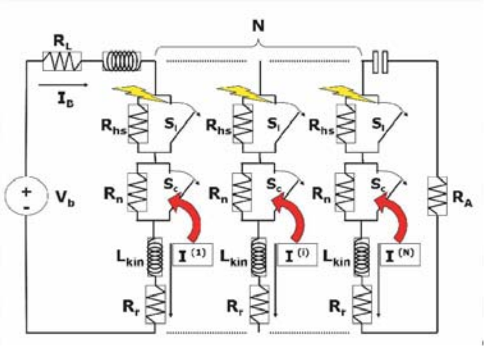
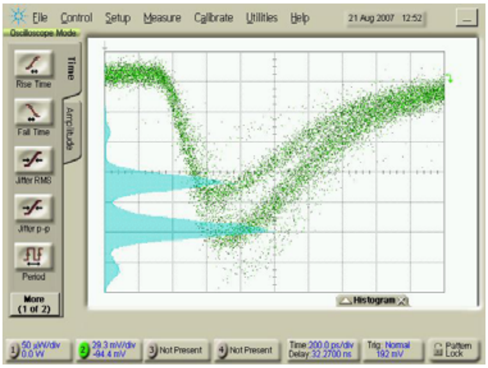


Fig. 1. Equivalent circuit of a PND



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1 50 μW/div 0.0 W

2 29.3 mV/div -94.4 mV

3 Not Present

4 Not Present

Time 200.0 ps/div Delay 32.2700 ns

Trig: Normal 192 mV

Fig. 2. Oscilloscope histograms during photodetection by a PND with 4 parallel wires. Up to four photons are detected.

The length of each nanowire ranges from 25 to 100 μm. Designs with and without the integrated bias resistors were tested.

The photoresponse of a PND with four parallel wires probed with light at 1.3 μm was recorded by a sampling oscilloscope (Fig. 2). All four possible amplitudes can be observed. The pulses show a full width at half maximum (FWHM) as low as 700 ps. PNDs showed counting performance when probed with light at 26 and 80 MHz repetition rate, outperforming any existing PNR detector at telecom wavelength by three orders of magnitude.

The one-photon quantum efficiency η at 1.3 μm and dark-counts rate DK were measured as a function of bias current. The lowest DK value measured was 0.15 Hz for η~2% (yielding a noise equivalent power *NEP*=5.6x10^{-18} W/$Hz^{1/2}$), limited only by the room temperature background radiation coupling to the PND. Additionally, unlike most PNR detectors, no multiplication noise can be observed in PNDs, as the width of the histogram peaks is independent of the number of detected photons.

In conclusion, a new photon-number-resolving detector, the Parallel Nanowire Detector, has been demonstrated, which significantly outperforms existing approaches in terms of sensitivity, speed and multiplication noise in the telecommunication wavelength range. The ability to measure the photon number is a key asset in quantum optical information processing, where states with a well-defined photon number are routinely used for the transmission and processing of quantum information. Additionally, by further extending this concept we envisage the fabrication of analog detectors with large dynamic range (>30 photons) and single-photon sensitivity, which would bridge the gap between conventional detectors and single-photon detectors, for applications in optical sensing and communications.

References

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