Development of Terahertz Photon Counting Detectors

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For future terahertz astronomy, we are working on a new interferometer technology based on the Hanbury-Brown and Twiss intensity interferometers. The intensity interferometers can be used with direct detectors and their correlation is stable against phase fluctuation. For application to space interferometers, direct detectors can operate under background limited performance which surpass the sensitivity of heterodyne receivers. Figure 1 shows the requirements on detector noise equivalent power (NEP) to achieve the background limited performance as a function of detector time response [1].

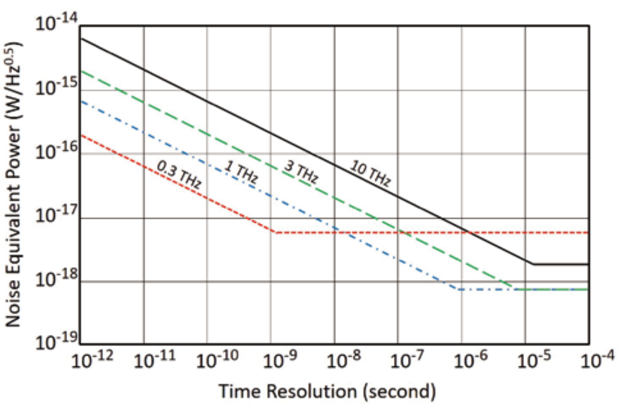

Figure 1: Requirements on background limited detector NEP as a function of the detector time response [1].

When the detector response is slower than a photon arrival rate, the required NEP is a function of input radiation power (right hand side in Figure 1). On the other hand, when the detector response is fast enough to resolve each photon arrival, the requirement on detector NEP is reduced in proportion to square root of the time resolution. For example at 1 THz, 1 ns time resolution enables the usage of detectors with NEP less than 10^{-17} W/$\sqrt{\text{Hz}}$. Under lower background conditions using grating spectrometers, the requirement on NEP do not change, and background limited performance is realized relatively easily.

We are developing terahertz photon counting detectors with high time resolution using superconducting tunnel junction detectors, similar to SIS receivers for ALMA. When niobium tunnel junctions are cooled below 0.8 K, they can be used as high sensitivity photon detectors [2]. Our group in NAOJ collaborating with AIST is developing low leakage tunnel junctions made of Nb/Al-AlOx/Al/Nb, and achieved 7 pA leakage current for 10 μm × 10 μm junctions. With smaller junction sizes, we expect to achieve as low as 1 pA leakage current as well as NEP less than 10^{-17} W/$\sqrt{\text{Hz}}$.

We have made an experiment using Nobeyama Radioheliograph to demonstrate the capability of the intensity interferometers [3]. Figure 2 shows the cross-correlation of signals from two 17 GHz receivers; one in amplitude and another in intensity (amplitude squared) correlations.

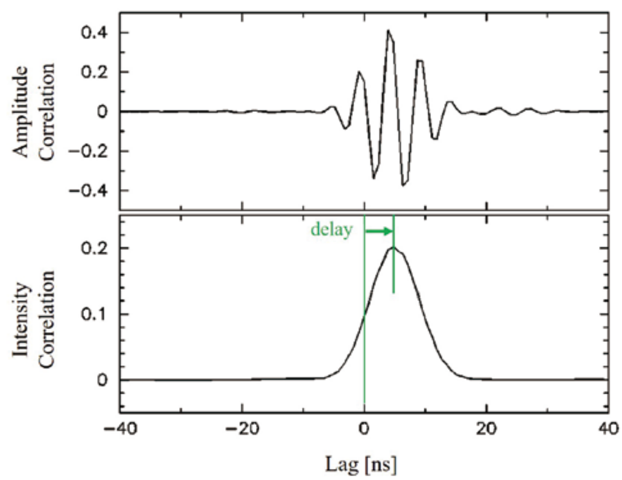

Figure 2: Amplitude and intensity (amplitude squared) cross correlation using Nobeyama Radioheliograph 17 GHz receivers [3].

Although in intensity there are no phase information, delay time can be measured by the intensity cross correlation, which can be used to define the complex visibilities. The same principle can be used in terahertz intensity interferometry, where fast photon counting detector are used to measure the intensity cross correlation and realize wide bandwidth and high sensitivity interferometers.

Astronomical observation using photon counting detectors can be a new tool to study photon statistics of astronomical sources [1]. In case of thermal source, Bose-Einstein statistics is expected which can be a precision measure of the source temperature, whereas in maser and synchrotron sources the photon statistics could tell us the physical condition of the sources.

References

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[2] Ezawa, H., et al.: 2016, *J. Low Temp. Phys.*, **184**, 244.
[3] Ezawa, H., et al.: 2015, *Proc. ISSTT-2015*, W2-2.