New interferometric aperture masking technique for full transverse beam characterization

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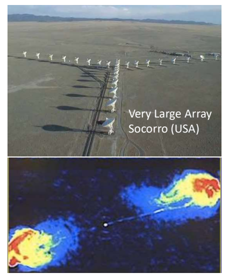
Abstract

Emittance measurements using synchrotron radiation areusually performed using x-rays to avoid diffraction limits. Interferometric techniques using visible light are also used to measure either the horizontal or the vertical beam projection. Several measurements rotating the interferometry axis are needed to obtain a full beam reconstruction. In this report we present a new interferometric multi-aperture masking technique and data analysis, inspired by astronomical methods, that are able to provide a full 2-D transverse beam reconstruction in a single acquisition. Results of beam characterization obtained at ALBA synchrotron light source will also been shown.

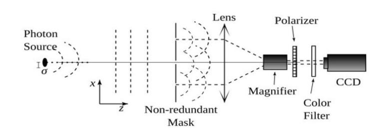
Introduction

During the last year, we developed full 2D characterization of the ALBA electron beam using single visible light interferograms with multi-aperture masks (from 2 to 7-holes) [2-3].
In these masks, the vector (baseline) between every pair of holes is unique, whence the term *Non-Redundant Aperture* (NRA).

The techniques employed are used in astronomical interferometry, including large arrays of radio antennas as well as optical masking interferometry. We have extrapolated and combined these techniques, allowing for unique application in the case of very bright laboratory optical light sources, such as the ALBA synchrotron light source.

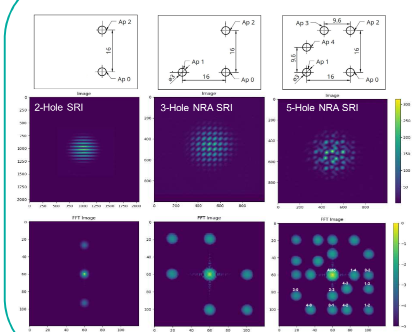


Experimental Set-up



Experimental set-up. The mask is exchanged to perform different either NRA or rotating SRI 2-aperture inteferometry

Coherence Model



Each baseline between every pair of apertures in the mask is unique, each spatial frequency in the Fourier domain is measured by only a single pair of apertures in the mask. We can identify the discrete peaks in the Fourier space with the pair of apertures in the mask.

This allows to infer the visibilities V_{ij} between apertures i and j by summing up the the complex sum within the circle of the peak.
The Visibilites depend on the degree of coherence γ and the intensities I going through each aperture i:

$$\|V_{ij}\| = \gamma_{ij}\|G_i\|\|G_j\|\,,\qquad \|V_{\mathrm{auto}}\| = \sum_i \|G_i\|^2\,,$$

where γ_{ij} is the coherence at the Fourier coordinates uij, vij of the i, j peak, and V_{auto} is the central peak in the 2D power spectrum.

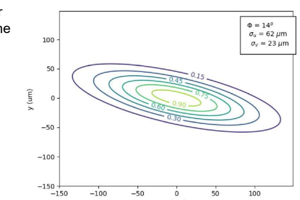
Assuming a Gaussian beam, the Coherence can also be taken as a 2D Gaussian, and so:

$$\gamma(u, v) = V\exp[-(au^2 + bv^2 + 2cuv)]\,,$$

This provides coherence $(\sigma_u, \sigma_v, \theta)$ of the Coherence, from where the e-beam parameters $(\sigma_x, \sigma_y, \theta)$ are inferred:

$$\sigma_x = \frac{\lambda L}{2\pi\sigma_u}$$

Note that this model includes 3 unknown parameters from the electron beam $(\sigma x, \sigma y, \theta)$, plus the N gains (or intensities) Gi coming from the mask itself. So we need 5-holes to fully reconstruct the beam ellipse using one interferogram.

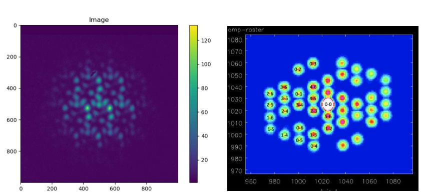


Beam ellipse obtained after the 5-hole NRA interferogram image.

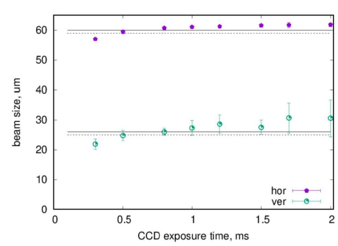
Results with 7-hole NRA

In order to improve the resolution, we perform several tests using a 7-hole NRA and λ=400nm.

- 7-hole NRA
- Decrease wavelength to λ=400nm
- Use special (from Astronomy) library to generate visibility, fit data and obtain the beam size

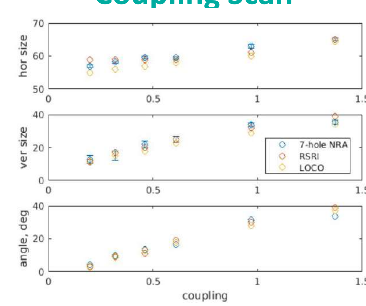


Exposure Time Scan



Exposure time scan compared with measurements using the RSRI (dashed line) and using the emittance from the ALBA pinholes (continuous line).
Larger exposure time are influenced by the vibrations in the light arriving at the CCD, which produce decoherence and increase the apparent beamsize.

Coupling Scan



Comparison of the horizontal beamsize (top), vertical beamsize (middle) and tilt angle (bottom) of the electron beam while changing the beam coupling using the skew quadrupoles. We compare the data using the 7-hole NRA with values inferred from RSRI and LOCO

CONCLUSIONS

This reports presents a new method to fully reconstruct the 2D transverse distribution of the electron beam using the interferometry produced by the synchrotron radiation and a multi-hole Non-Redundant Aperture (NRA) mask. Using a minimum of 5-hole apertures mask, the electron beam can be characterized with only one interferogram, which means that can be used for real-time applications. In order to evaluate the technique to different beam sizes, the beam coupling in the machine has been using the skew quadrupoles. The measurements for using the 7-hole NRA mask were in agreement with the results given by well-established methods (RSRI and LOCO), and it provided reliable measurements within a range of ~10μm (smallest achievable vertical beam size) to around 70μm.

REFERENCES

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3. B. Nikolic, C. Carilli, L. Torino, U. Iriso, and N. Thyagarajan, Two-dimensional Electron Beam Characterisation from a Single Interferogram, submitted to PRAB (2024)..