Near-field antenna pattern measurement and holographic phase retrieval of a LiteBIRD high frequency telescope optical model

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INTRODUCTION

The LiteBIRD space mission is aimed at detecting B-mode polarization in the CMB that would contain crucial information about the inflationary universe. We applied the same methodology used to study the Low Frequency Telescope to characterize an optical prototype of the High Frequency Telescope (HFT). We measured its antenna patterns using near-field vector measurements and explored the possibilities of holographic phase retrieval methods.

Experimental setup

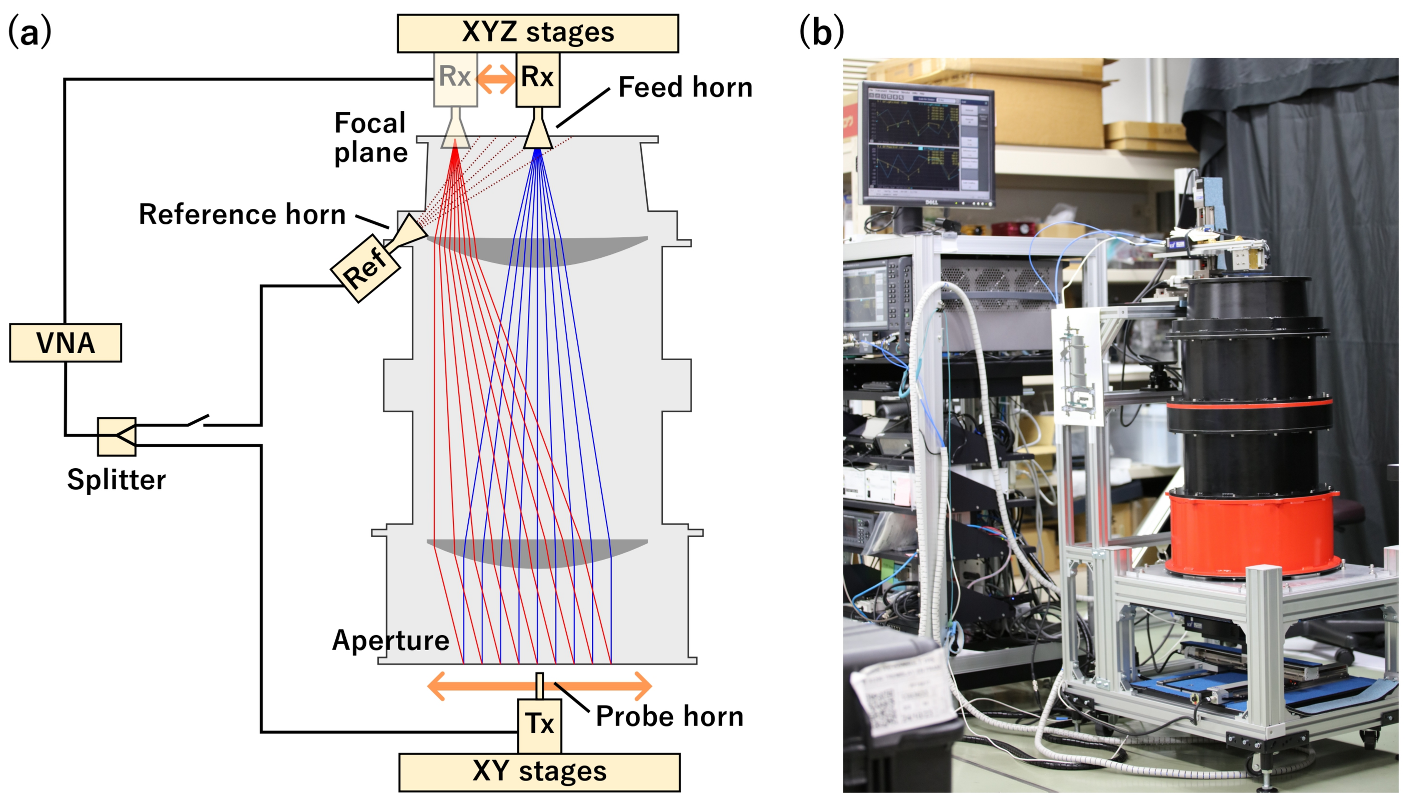

Figure 1 : (a) Schematics of the measurement setup (b) picture of the setup with the HFT optical prototype in black and red

The optical prototype is composed of two High Density PolyPropylene lenses, designed to mimic the optical properties of the cryogenic HFT at ambient temperatures. Signal at 140-220 GHz is emitted by a VNA coupled to a probe horn. The probe horn scans the planar near-field space using high precision XY stages. The antenna response is measured by the feed horn and the VNA. A reference horn is added for holographic measurements.

Methods

The near-field method for antenna pattern measurement uses the 2D Fourier transform to evaluate the far-field pattern F from a well resolved near-field measurement E :

$$F(u,v,\omega) \propto \iint E(x,y,\omega)e^{jk(ux+vy)}\,dx\,dy$$

The measurements are also calibrated thanks to periodic reference measurement at the center of the XY plane during its scanning. We deconvolve the probe beam's response using an approximate formula that restricts us to **θ ≤ 60°.**

The holographic phase retrieval method relies on using a reference signal that is going to interfere with the signal coming from the aperture. This interference pattern allows us to retrieve phase information even when we can only measure the intensity of the signal, which will be the case when testing with realistic LiteBIRD detectors. This interference pattern, called hologram, is studied using the inverse Fourier transform over the different frequencies at which we made the measurement.
We have also explored other tools to analyze the time-delay spectra of the signal, such as using the Continuous Wavelet Transform (CWT) to perform diagnostics of the frequency-time behavior of the optical system.

MEASUREMENTS

Presented here are the main results for the near-field measurements as well as our best attempt at holographic phase retrieval.

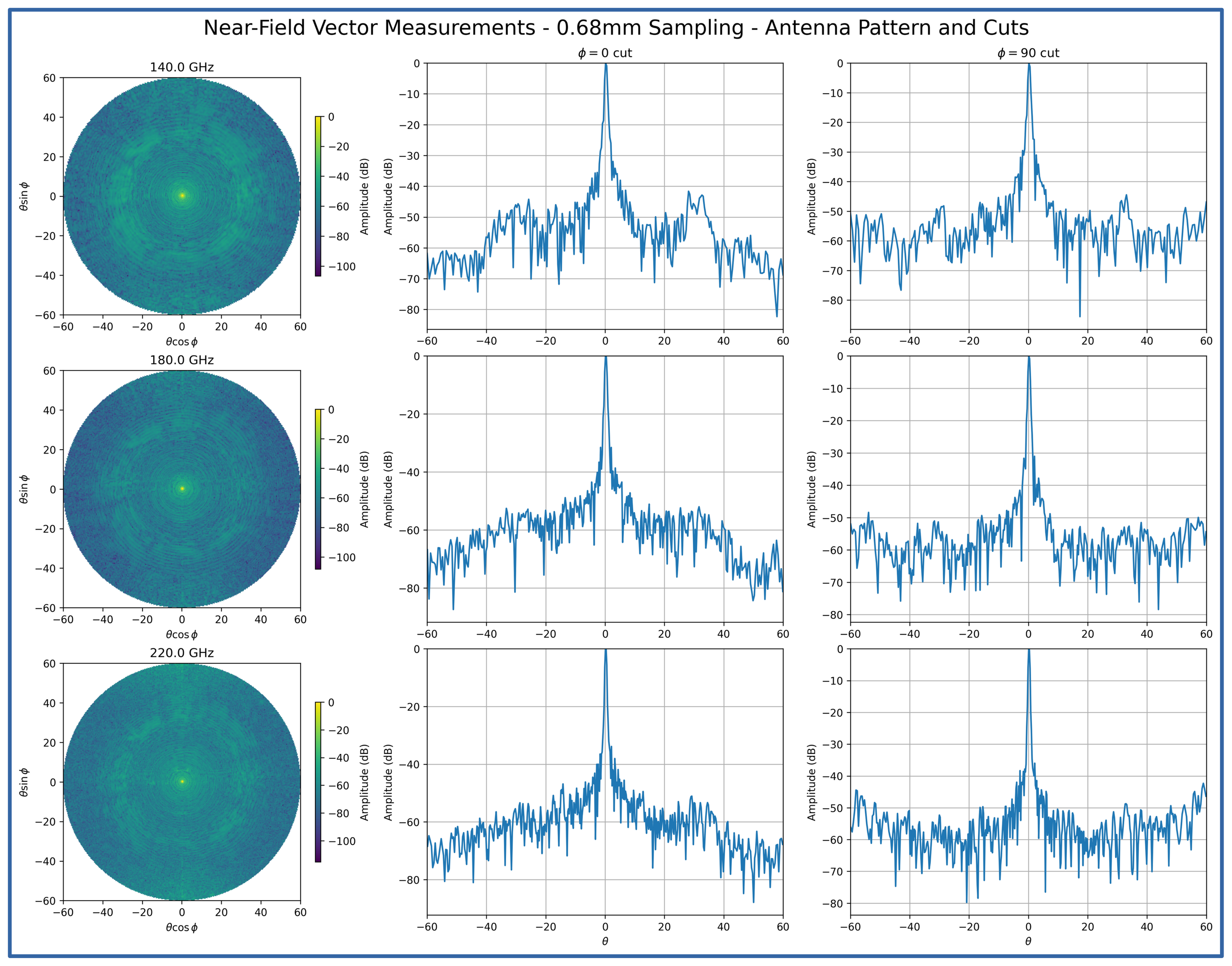

Figure 2 : Antenna patterns and cuts for near-field measurements.

We used a **0.68 mm spatial resolution** to sample the XY plane, as well as measuring **21 frequencies across the 140-220 GHz range**. The dynamic range of this measurement goes **up to -80 dB**, with some apparent side-lobe patterns at **θ ≈ 30°** and with a relative intensity compared to the main lobe of **-50 dB.**

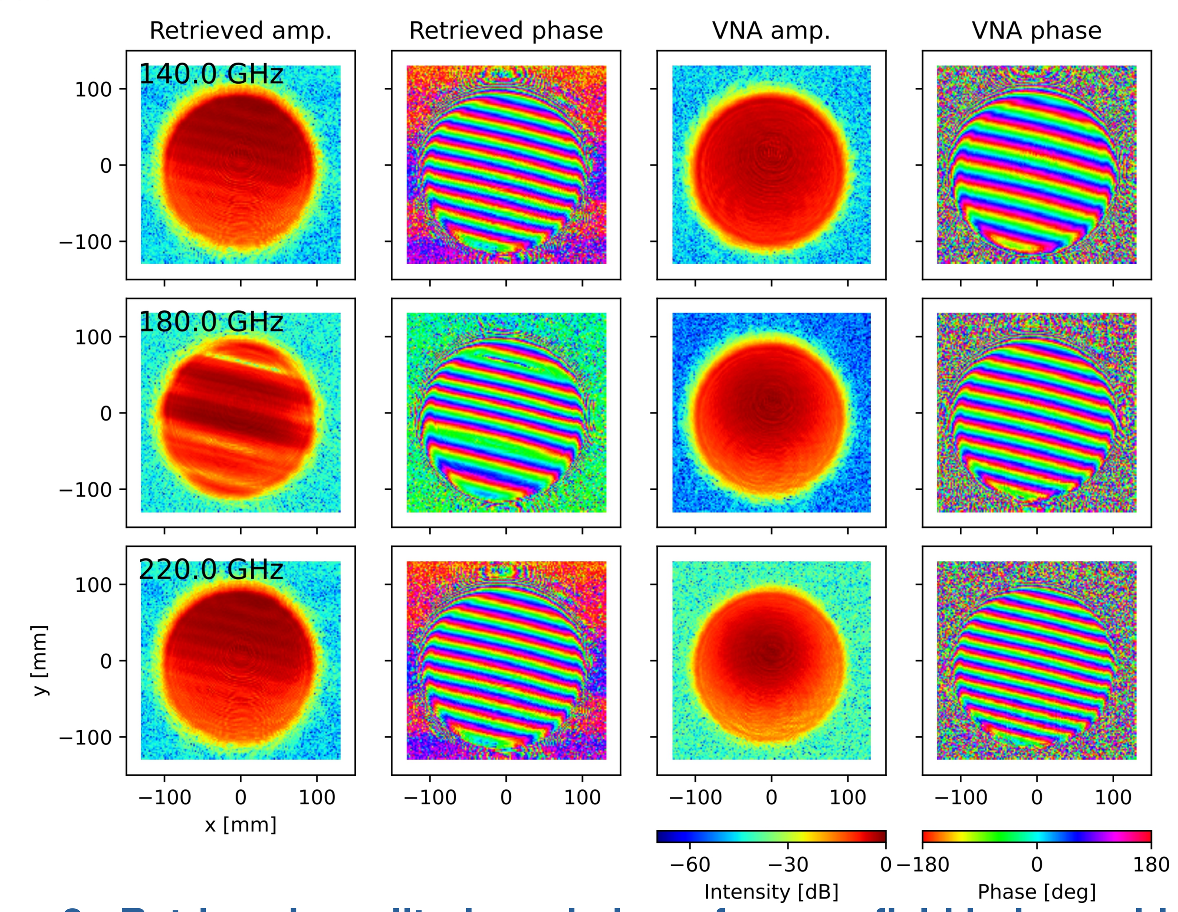

Figure 3 : Retrieved amplitude and phase for near-field holographic measurements, compared with the reference VNA signal

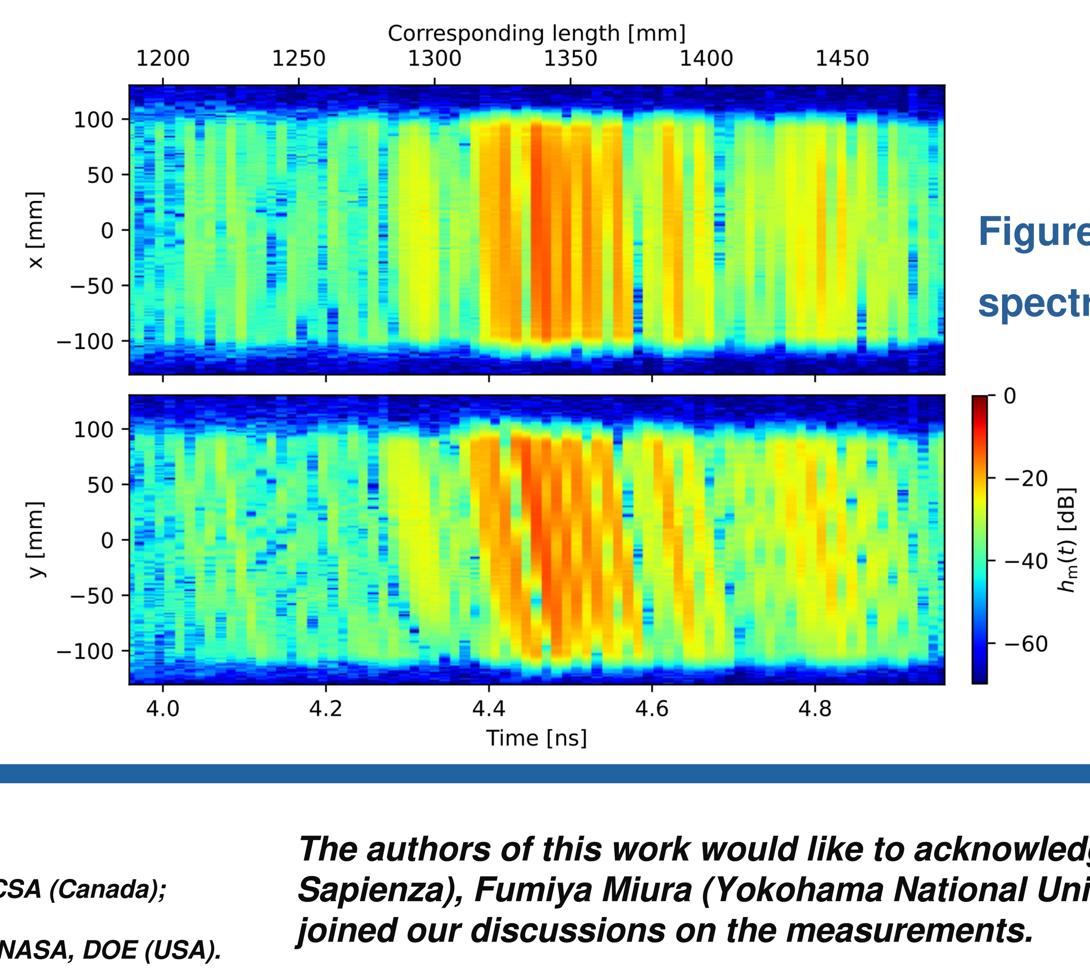

Figure 4: Time-delay spectra of the hologram

DISCUSSION

We computed the residuals between two nearly identical near-field measurements to estimate the robustness of the measurement setup as well as the influence of some **systematical effects.**

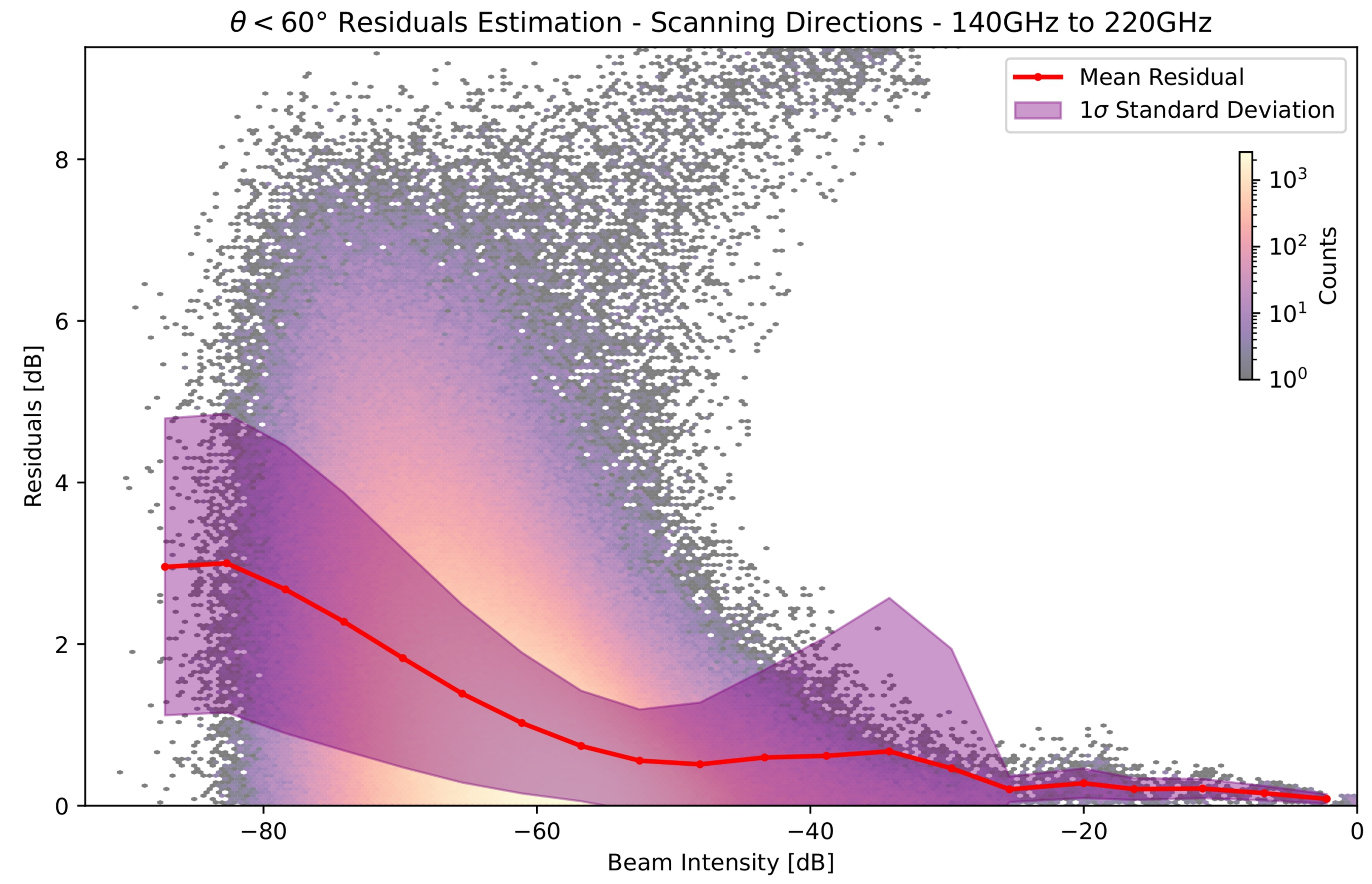

Figure 5 : Residuals estimation between two measurements.

- The **main lobe** area (Beam intensity ≥ -20 dB) has **residuals under 1 dB**, with a small standard deviation
- The **far side lobe area** (Beam intensity ˜45 dB) has **residuals around 1 dB**, with a larger standard deviation than the main lobe.

This analysis and the fact that we find results similar to optical physics simulation of the system prove the quality of the measurement method.

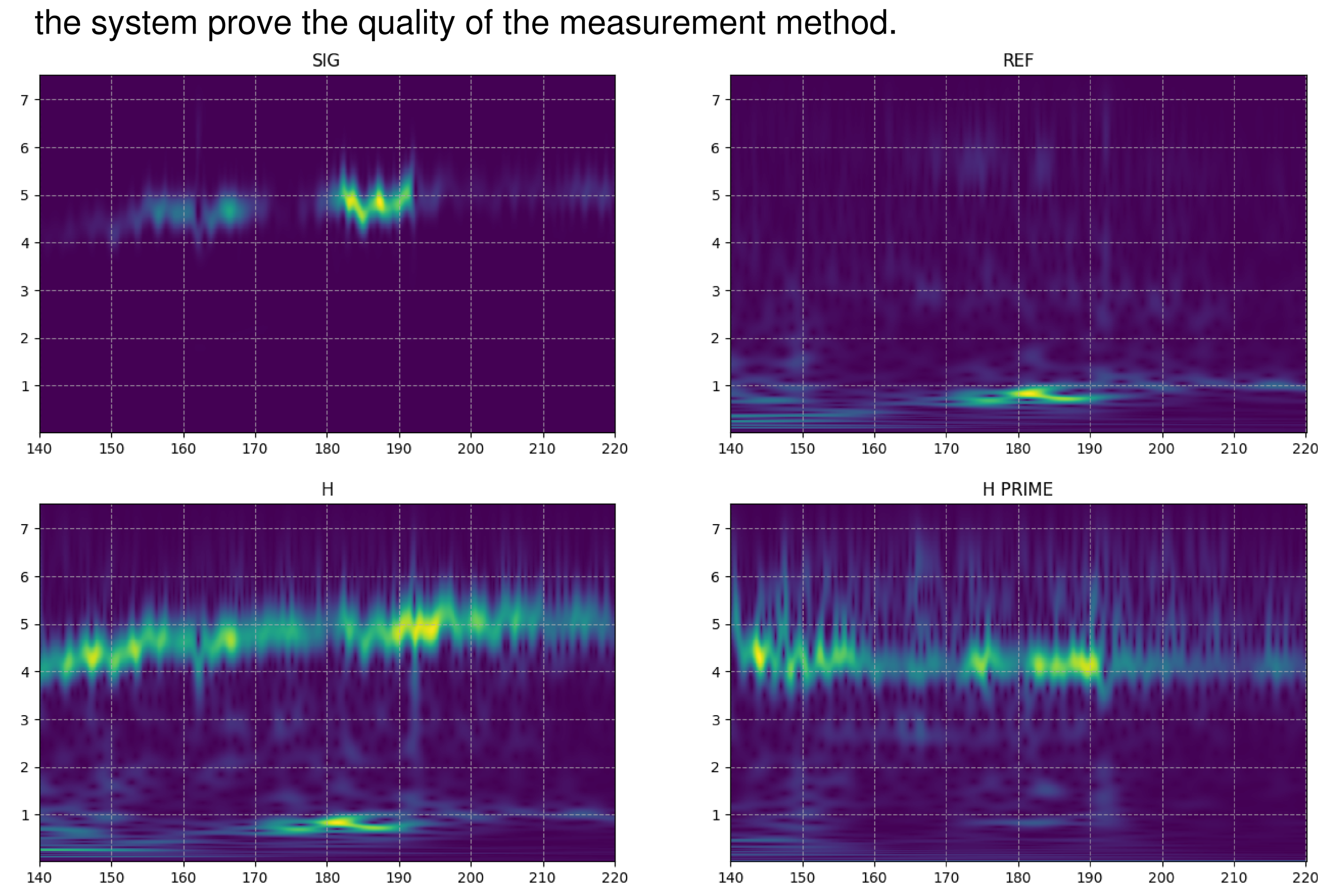

Figure 6 : CWT power spectrum of the different measurements for the holographic phase retrieval methods.

The CWT power spectra allow us to look into the details of the response of the optical system for each frequency. Using this tool, we were able to **identify resonant frequencies in the system**, possibly due to standing waves. The horizontal lines on the bottom left of the spectra are standing waves happening inside of the coaxial cable, whose length match the corresponding time-delay.

CONCLUSIONS

We have verified the optical design of the HFT by near-field measurements and obtained consistent and accurate measurements of far-sidelobe patterns.

We have investigated the feasibility of the near-field and holographic phase-retrieval techniques applied to the HFT and identified limitations and possible future improvements for the data analysis pipeline.

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The code used for this work will be made available over at github.com/ecarinos/nearfieldpy