Frequency Resolving Spatiotemporal Wavefront Sensor

(Sideband Camera / Wavefront Camera)

Go Keisuke Goda

David Ottaway, Blair Connelly, Rana Adhikari, Nergis Mavalvala

March 18, 2003

LIGO MIT Laboratory

Center for Space Research

Massachusetts Institute of Technology

LIGO-G030114-00-Z

Motivation

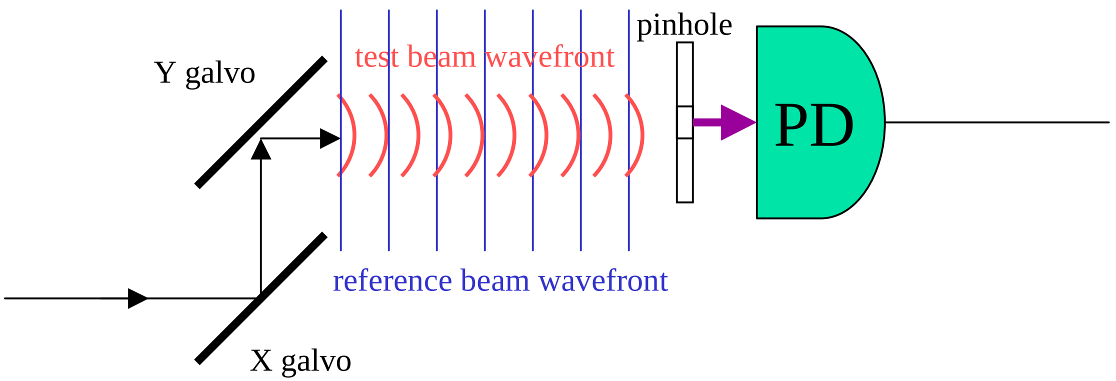
- In-situ measurement on the LIGO interferometers revealed large mysterious fluctuations in the relative amplitude of the RF sidebands
- This compromised proper operation of the wavefront sensing automatic alignment system
- So knowledge of the behavior of the sidebands became crucial
- However, because RF sidebands are typically ~100 times weaker than the carrier in LIGO, it is difficult to measure the amplitude and phase of each sideband

What is the wavefront camera?

- **The wavefront camera**

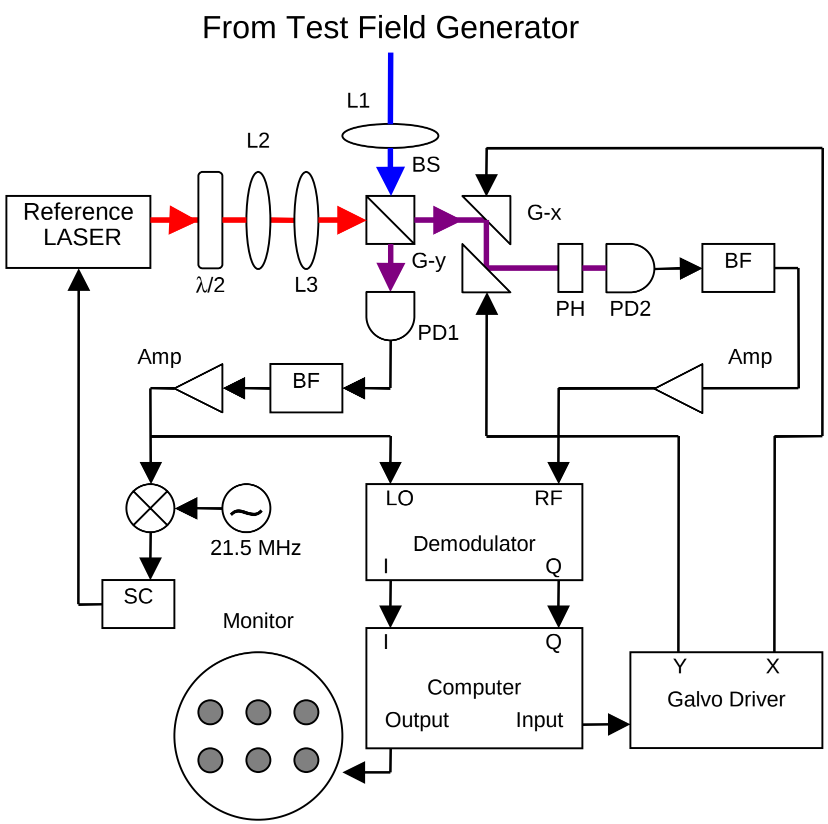
  measures the spatial amplitude and phase variations of a test laser beam's weak sidebands in presence of a strong carrier at a different frequency

- **How it works?**
  - Measures the spatial amplitude and phase of a sideband of a test field
  - The test field is superposed on a reference field
  - Two galvanometers move the beams over the surface of a photodetector for measurement



Experimental Setup

(Wavefront Camera)



Reference Laser:

independent reference laser (Nd:YAG)

Beam Expander (L2 & L3):

makes the waveftont of the reference field very large at PD2

- Beam spot size of Test Field: 10.0 mm
- Beam spot size of Reference Field: 35.0 mm

X and Y galvos (G-x & G-y):

do spiral scans

Pinhole (PH):

tramsmits the combined beam at only one pixel
(pinhole diameter = 150 μm)

PD1:

detects the beats → the LO port of the demodulator

PD2:

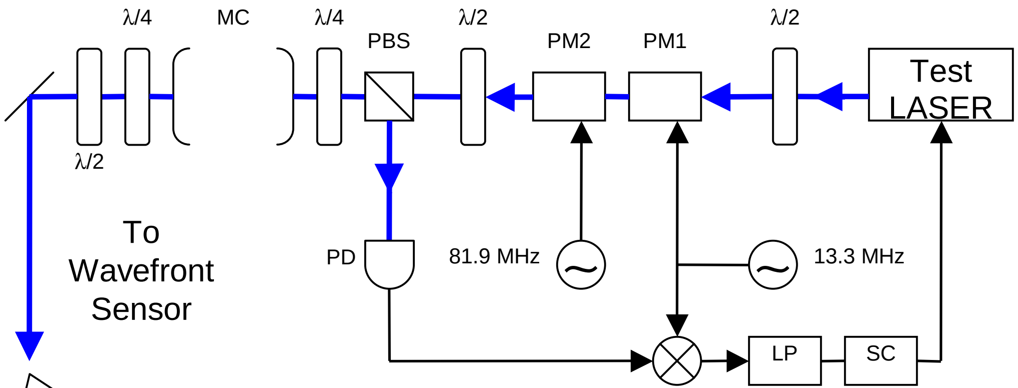
contains spatial information of the test laser beam → the RF port of the demodulator

Demodulator:

calculates I-phase and Q-phase

Experimental Setup

(Test Field Generator)

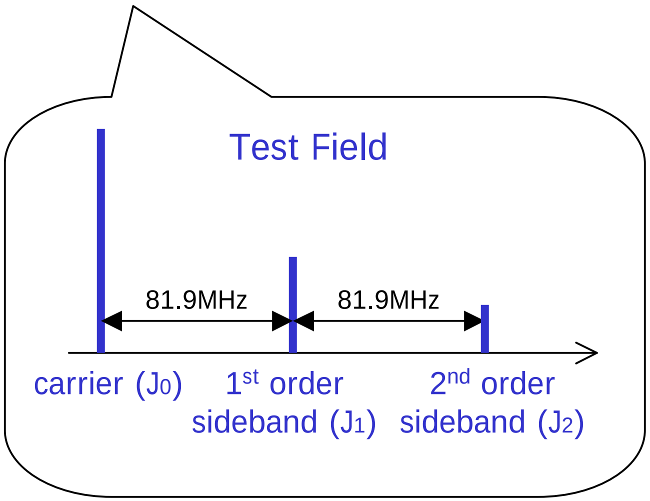


Test Laser:

frequency-stabilized test laser (Nd:YAG) with frequency modulation at 81.9 MHz

Mode Cleaner:

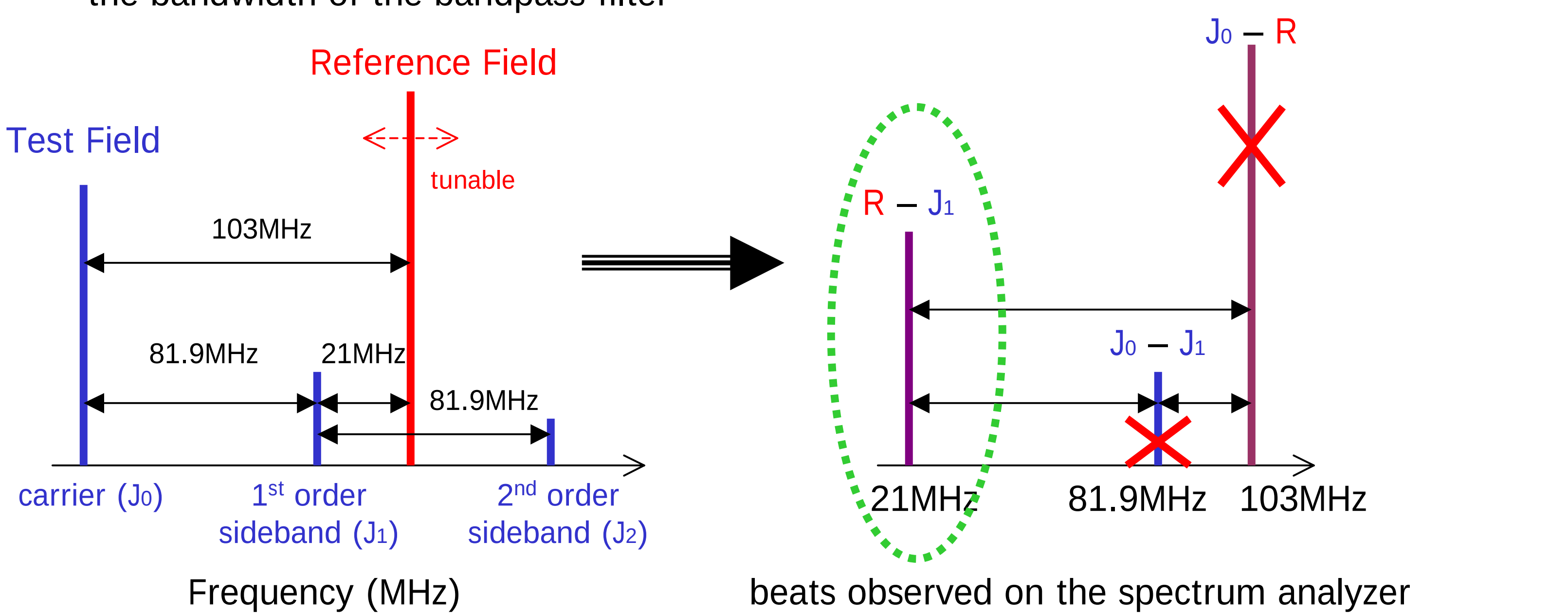
rejects all the dirty modes other than the carrier (TEM00), the 1st order sideband (TEM21), the 2nd order sideband (TEM42), and so on



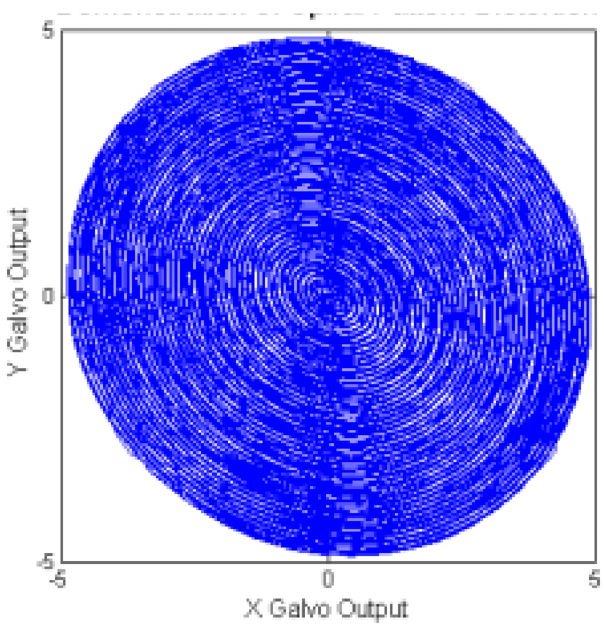
To test the effectiveness of the wavefront camera, an arbitrary optical field with a well-known spatial mode of slightly different frequency and significantly lower amplitude.

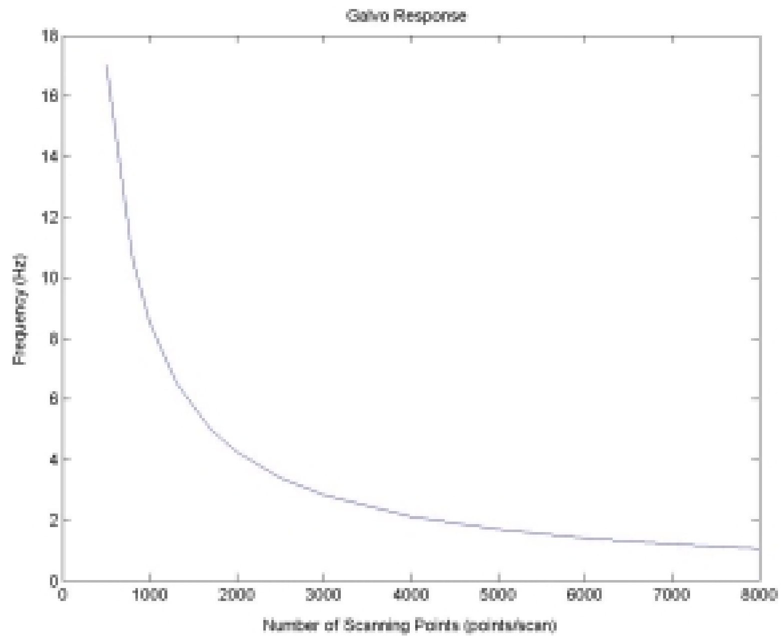
Frequency Tuning Techniques

- **PD1 and PD2:**
  detect the test field on top of the reference field
- **Bandpass Filter @ 21 MHz:**
  eliminates all the unnecessary frequencies other than 21 MHz
- **Reference Field Frequency:**
  is tuned so that the beat between the sideband of interest and the reference field is within the bandwidth of the bandpass filter



Galvo Scan





- Pattern pictured shows the galvo response for 8000 points at 1 Hz
- Spiral is distorted due to a lag in the y galvo
- Data still valid since galvo positions are read out directly
- Resolution can be enhanced by simply increasing the number of scanning points at the expense of the galvo scanning speed
- Speed is limited by the sample rate of the data acquisition system we used, but fundamentally limited by the inertia of the galvos

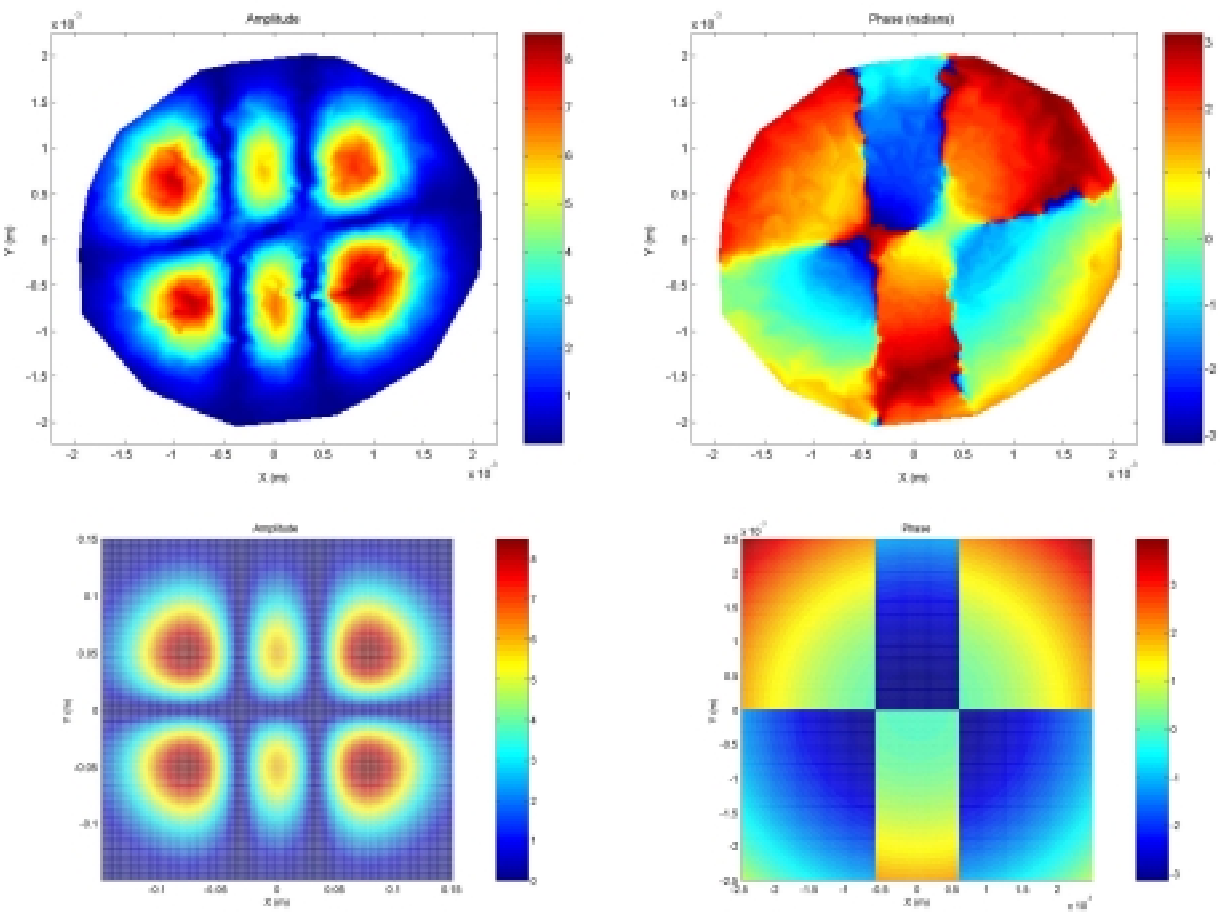
Result

(1st order sideband in the TEM21 mode, 25dB smaller than the carrier)

RF Amplitude | RF Phase

Experiment

Theory



Conclusions

- We experimentally demonstrated the wavefront camera and obtained the images of the phase and amplitude of the 1st order sideband (25 dB smaller than the carrier)
- The experimental results are qualitatively in good agreement with the theoretical predictions
- The wavefront camera is useful for measuring the spatial variation of the phase and amplitude of a weak sideband and has been used on the LLO interferometer for alignment
- Installation of the wavefront camera is being planned for the other interferometers