KECK Interferometer

The control system for the Keck interferometer nuller

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Introduction

- Linking the two Keck 10m
  - 85m baseline
  - J/K/N band operation
  - Visible AO
- Nuller
  - N band combiner
  - Null starlight to allow circumstellar material detection
  - Science goals:
    - Survey of exozodiacal light in nearby stars
  - Technical goals:
    - Better that 100:1 raw nulls
    - Sources down to 2Jy
- Control system
  - Precision mode of the instrument

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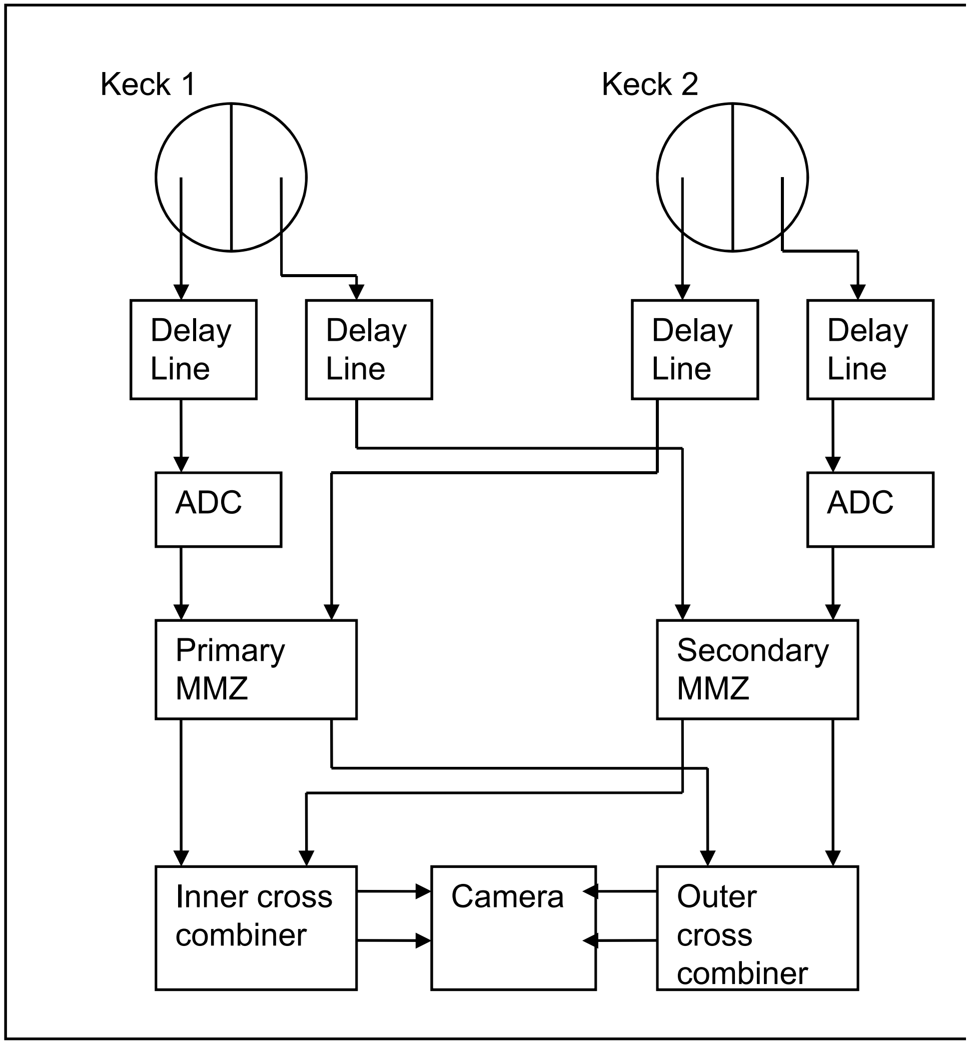
Contents

- Overview of the nuller system
- What's special about the nuller control?
- Details of the nuller control implementation
  - Nuller control itself
  - Interactions with the rest of the control system
  - Interesting new things we did while implementing nuller control
- Plans for the future

- See also:
  - Colavita et al this conference – more details overall
  - Serabyn and Koresco this conference – science results
  - Garcia et al conference 2674 – s/w oriented description

System overview

- N band components only
- See Colavita et al for details
- Modified Mach-Zehnder (MMZ) combiners combine light from ½ each telescope
- Cross combiners (XC) combine two halves same telescope (~5m baseline)
- Atmospheric dispersion correctors (ADC) for broad band

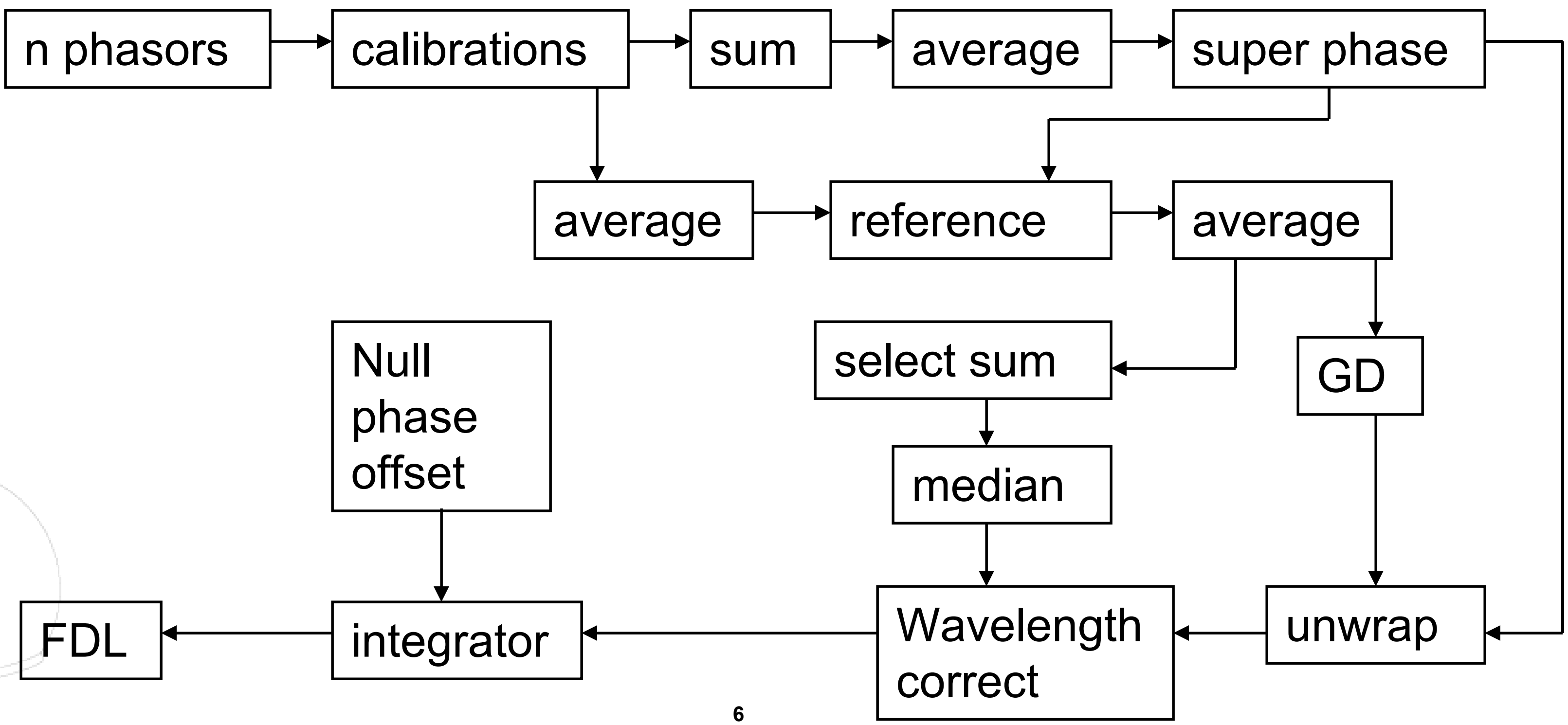


Unique problems

- Precision
  - 100:1 raw nulls require accurate phase control (rms<100nm) at high frequency
  - Solution: great care in implementation
- Control bandwidth
  - Targets too faint (low SNR) for fast feed back control at 10μm
  - Solution: feed forward from form 2μm fringe trackers
- Spectral Bandwidth
  - 8μm to 12μm with water vapor path mismatch and seeing
  - Solution: active dispersion control
- Only leakage fringe signal at null
  - So directly tracking the phase and dispersion errors is difficult!
  - Solution: Interleaving science and control in fast switching sequence

Feed Back Nuller OPD Control

- Low bandwidth to provide accurate average null
- Single MMZ control
- Single wavelength scan, 4 bin, active tracking, like K band
  - Four bin intensities lead to fringe phasor giving fringe amplitude and phase.
  - Fourier transform of phasor vs wavenumber give group delay

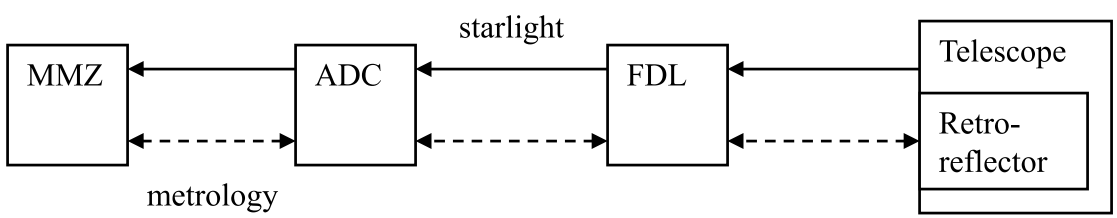


Feed Back Nuller OPD Control

- Calibrations
  - Dark: from off fringe data
  - Dewarp: phasor pixel wavelength ≠ modulation stroke
  - Weight: pixel intensity
  - Derotate: slew timing across detector array
- Null phase offset
  - Empirical determination
- Bandwidths
  - Set by temporal averaging
  - Phase longest $\tau = 8s$
  - GD longest $\tau = 120s$

Feed Back Nuller Dispersion Control

- Feed back difference of GD and super phase to glass ADC
  - Ensures minimum slope phase vs wavenumber
- Phase curvature allows family of local minima
  - Best null for minimum curvature
- Control approach:
  - Empirical determination of internal zero point
  - Feed forward prediction from known astrometric optical path mismatch and measured water vapor content
  - Limit servo to single wave offset to prevent random walk
- Orthogonalize FDL OPD and ADC dispersion control
  - FDL internal servo measures ADC encoded position



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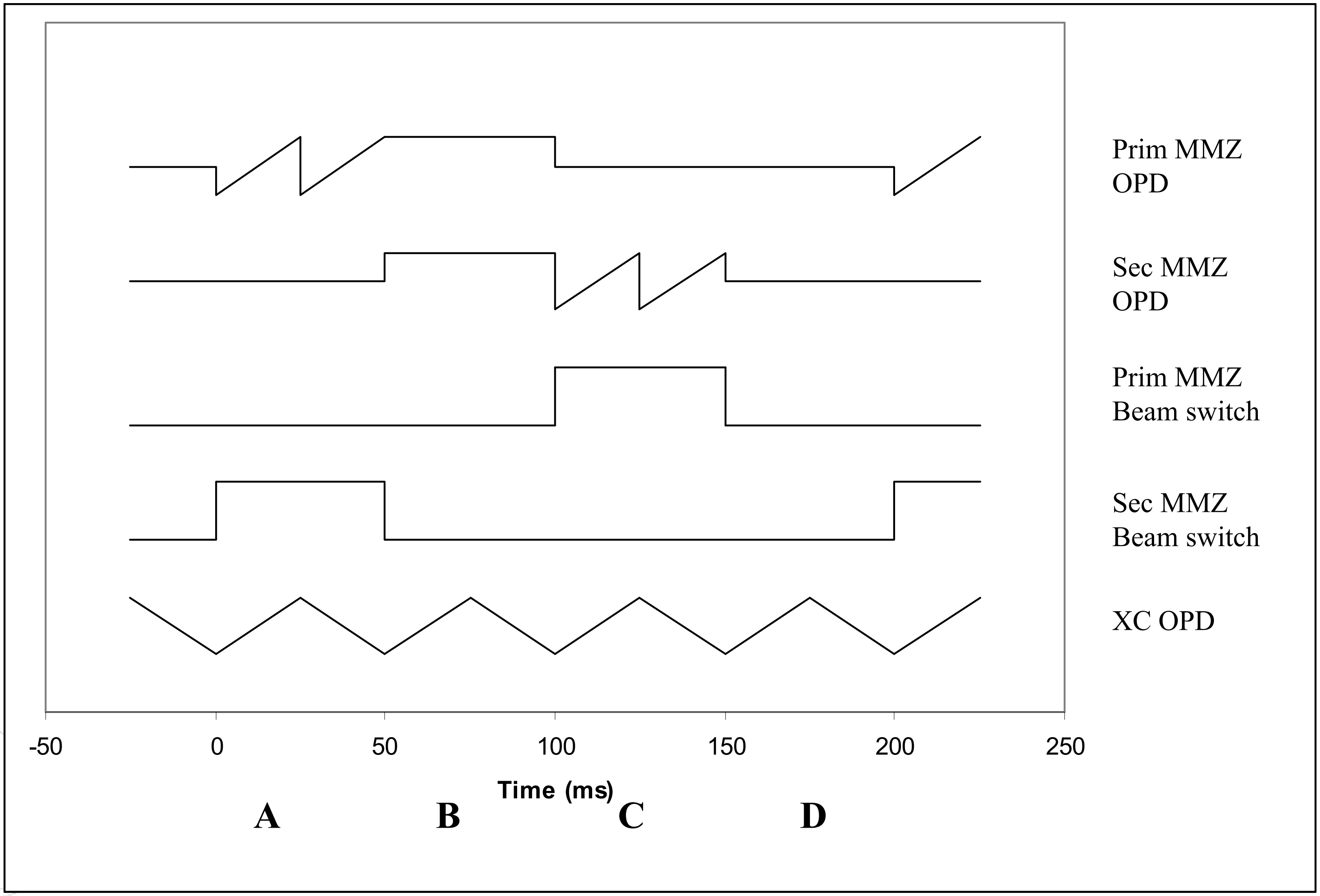
Feed Back Cross Combiner Control

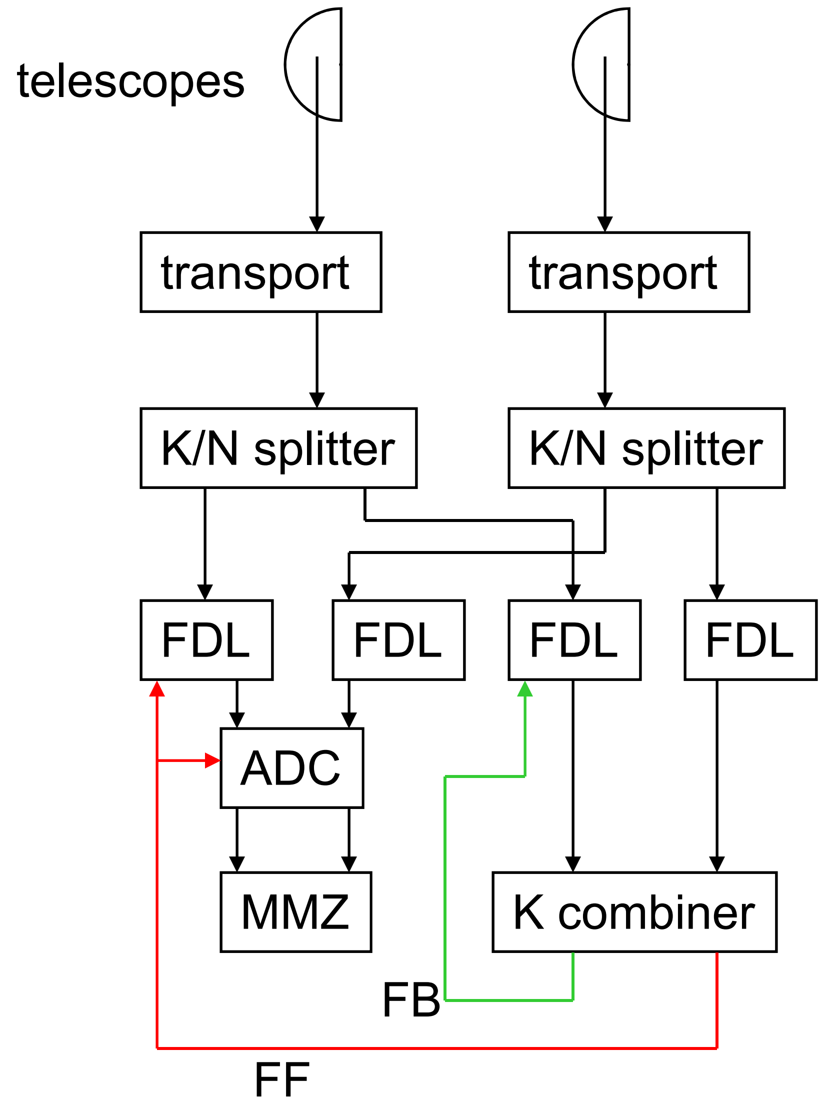
- Done after both MMZs are phased
- Offset MMZ track points by π to give constructive fringe
- Four bin single wavelength modulation algorithm
  - Triangle wave rather than sawtooth
  - (Large (2”) actuator mirror)
  - Calibration separately maintained for upstroke and downstroke
- XC tracked directly on GD measurement
  - Avoid unwrapping issues
  - SNR high enough at low bandwidth

Fast Sequencing



Feed Forward Control

- Phase and GD measure from K band system
- K band system normally used for traditional V^2 science
- Control
  - Normal FB control to K band FDLs
  - FF to FDL for MMZ OPD
  - FF to ADC for MMZ dispersion
  - Low data latency
  - High bandwidth



Components of OPD feed forward

- Integrated feed back offset
  - Same as sent to K band FDLs for closed loop control
  - Includes DC offsets to help nuller fringe search
- Dry air error feed forward
  - Full error feed forward without integration
  - Possible because no closed loop control
  - Reduces data latency
  - Requires hold behavior based of K band instantaneous SNR
- Additional component due to water vapor seeing effect on OPD differential due to K to N band refractive index change
  - Based on heavily temporally filtered K band GD and phase estimates
  - See Colavita et al, PASP, **116**, p876, 2004

Dispersion Feed Forward

- Difference of phase and GD estimates from K band, scaled for refractive index change
- AC part of signal only (DC from previous targets)
- Accounts for water vapor seeing effects on N band dispersion faster than closed loop feed back control

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Interesting Unusual Stuff

- Servo convergence for N band closed loop
  - Very long time for faintest sources
  - Several times e-fold times (8s phase, 120s GD)
  - Adversely affects on source science time
  - Solution: large single step from initial GD estimate
- Fast sequence feed forward control to MMZs
  - No closed loop control during null and peak periods
  - Thus can use partial error feed forward (no integrator) to reduce instantaneous phase error during science data
- Overlap algorithm for K band phase estimate
  - Use next available of 4 temporal bins to make composite phasor rather than waiting for complete set of 4 measurements
  - Can greatly reduce data latency for K to N feed forward
- Coadding K band spectral and white light data for higher phase SNR

Accomplishments

- See other papers by Colavita et al, Serabyn, and Koresco et al for details
- Better than 100:1 nulls consistently
- Tracking reliably for <5Jy sources
- Close to science requirements

Future Upgrades

- Use all 4 beams in to detector
  - Currently only 2
  - For control, just need to keep phasor sign straight
- Fast sequence duty cycle optimization
  - Spend more time on science data and less on fringe tracking?
- Null phase tracking
  - May be possible to track directly on phase error from null, rather than tracking MMZ absolute phase and using empirically measured null phase offset target.