Wavefront sensor design for NGAO: Assumptions, Design Parameters and Technical Challenges
Version 0.1

V. Velur
Caltech Optical Observatories
M/S 105-24, 1200 E California Blvd., Pasadena, CA 91125

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1 Introduction

The Next Generation Keck Adaptive Optics system is a multiple guide star Adaptive Optics system with a two stage reflective OAP relay designed to work between 100-170 nm wavefront error [1]. The system is envisioned to have four kinds of wavefront sensors, namely, one NGS WFS, 9 LGS WFS's, 3 TT(FA)s (2TTs and 1 TTFA), and one (or two?) truth sensor. This document describes the input parameters that feed into the WFS design for each of the aforementioned WFSs as part of task # 3.2.3.5 of the NGAO work breakdown structure.

2 WBS definition for 3.2.3.5

WBS Dictionary Entry: Develop a design concept for each of the required NGAO wavefront sensors:

3.2.3.5.1 High Order LGS Wavefront Sensors: Given the functional and performance requirements, develop a design concept for the laser guide star high order wavefront sensors. Take into consideration the possible need for both open and closed loop wavefront sensing.

3.2.3.5.2 High Order NGS Wavefront Sensor: Given the functional and performance requirements, develop a design concept for the natural guide star high order wavefront sensor(s). Take into consideration the possible need for both open and closed loop wavefront sensing. Include consideration of ADC packaging (ADC design is covered in WBS 3.2.3.8).

3.2.3.5.3 Low Order NGS Wavefront Sensors: Given the functional and performance requirements, develop a design concept for the low order natural guide star wavefront sensors for the purpose of determining tip/tilt and other low order modes in laser guide star observing mode. Take into consideration the possible need for both open and closed loop wavefront sensing. Include consideration of ADC packaging (ADC design is covered in WBS 3.2.3.8).

3.2.3.5.4 Calibration Wavefront Sensor: Given the functional and performance requirements, develop a design concept for the calibration wavefront sensor which will use natural guide star light as a truth wavefront. This sensor will be periodically used to reset the references of the high order wavefront sensors in laser guide star mode. Include consideration of ADC packaging (ADC design is covered in WBS 3.2.3.8).

3 Design considerations, Assumptions and design parameters

3.1 Design Considerations and Technical Challenges

3.1.1 High order LGS wavefront sensors

The LGS wavefront sensors sense modes higher than tip/tilt and provide tomographic information to the Real-Time computer system.

- **WFS FoR**There are a total of 9 LGS wavefront sensors out of which one is located in the center with five around it on a circle. The radius of this circle can vary from 10"-90". There are 3 more "roving beacons" that are used to sharpen tip-tilt stars for the TT(FA) sensors. As part of building a versatile system it is important to have these three beacons be point-able anywhere in a 101" radius field.
- **Tilted focal plane and shearing coma-corrector**The current optical design [2], [3] is such that the LGS focal plane is tilted and has some aberrations as the DM and OAPs are designed to work for celestial objects and not a 90-180 Km conjugate. The tilt and the amount of aberration change with zenith angle. The aberrations can be largely eliminated by using a comatic corrector plate, Brian suggests the use of a set of shearing spherical plates to create a coma-corrector with varying coma. The fact that the LGS focal plane tilt is also a function of the zenith angle means that each of the LGS WFS's must be on a separate linear stage or a hexapod with appropriate travel and tilt requirements.
- **Keeping the pupil on the lenslet** Since these WFSs are working with varying object distance it is essential to ensure that the pupil is on the lenslet. This has been previously achieved by modifying a Cooke triplet with a doublet and a translating singlet [4].
- **Object selection mechanism** The LGS WFSs have to be able to select stars and point and boresite themselves to image the wavefront. A OSM facilitates this and ensures that the WFSs are registered to the DM.
- **Moving focal plane** Lastly, the LGS WFSs need to translate to accommodate a focal plane that moves with zenith angle.
- **No MEMS baseline** As a baseline LGS WFSs will not be equipped with a MEMS corrector. But the design will not preclude addition of such a device at a later stage. But the design shall not preclude the addition of MEMS mirrors in the system.

Contribution(s) that are considered for spot size calculation The spot size for different WFSs at the detector is a combination of the following contributions:

1. Intrinsic object (LGS beacon) size

2. Imperfect uplink AO (only for LGS)
3. inherent aberrations in the uplink beam (only for LGS)
4. Beam movement contribution to uplink (estimated rms titlt difference between up and down links. Limited to LGS)
5. Residual seeing contribution to uplink (limited to LGS)
6. Natural seeing (with downlink compensation factored in)
7. AO WFS aberrations
8. Spot elongation (avg. elongation is used, limited to LGS)
9. Sub-aperture diffraction (if not pyramid WFS)
10. Atmospheric blur (not applicable to LGS)

3.1.2 High order NGS WFS

This is clearly the simplest and easiest wavefront sensor to design. By architecture definition it resides after the second relay and has to be able to pick off any field stars within a 40" FoR.

IR sensing issues The HgCdTe detectors facilitate non-destructive read outs while accumulating photons as they are capacitative in nature. The noise can be beat down by multiple Fowler samples as shown in Figure 1. Table 1 shows the time estimates required for different processes that constitute a readout process.

Operation	**Time (μsec**
Read out speed/pixel	10
Line skip	2
Pixel Skip	2
Frame read	20

Table 1: Time estimates for H2RG read out operation [7]

64x64 sub-ap read out [7] [9] Let us use a Hawaii1RG with 16 readout amplifiers. Since we have a 64x64 sub-aperture sensor, one channel or (amplifier) will have to read 8 $\times$ 128 pixels. One will have to read the chip at 100 KHz (10 e^{-} noise mode) instead of 5 KHz (30+ e^{-} noise mode). Each wavefront sensor frame consists of a "reset", "initial read" and a "final read". So the max. frame rate shall be given by:

$\frac{100*1000Hz}{1024*2}$ = 49 Hz + other overheads like line skip, pixel skip and frame read out time.

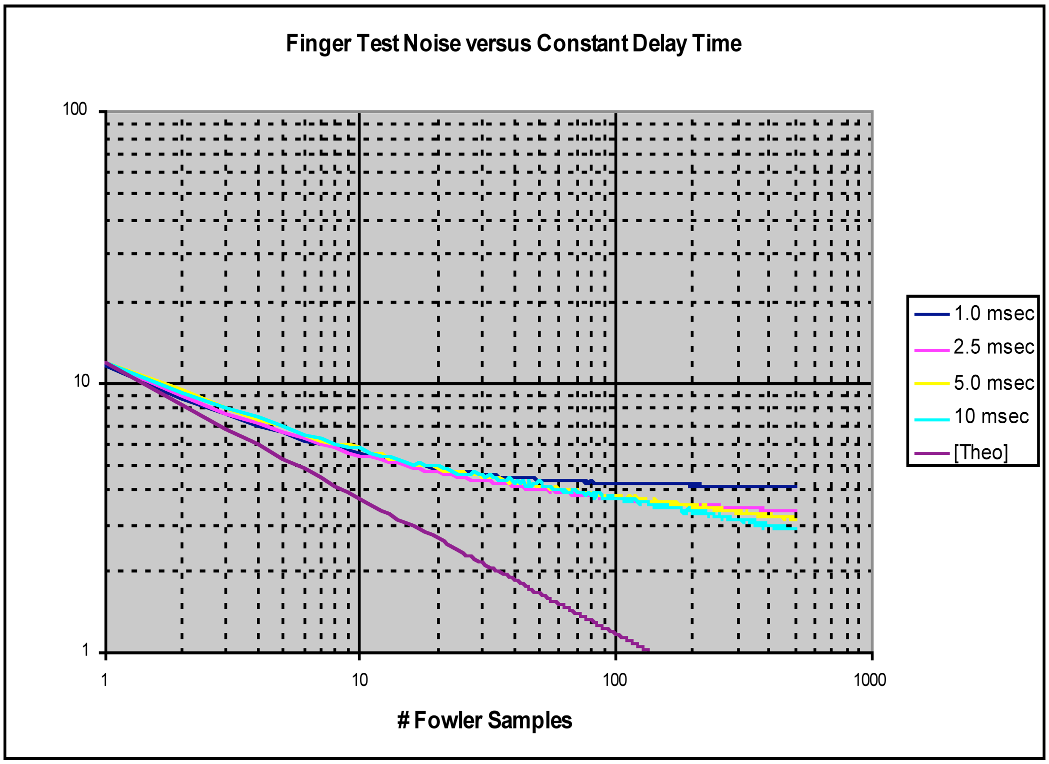

Figure 1: Noise vs. Fowler samples

Speedster and Gemini-ESO effort to make fast IR detectors One way to make fast IR detectors is to have many amplifiers or have a multiplexer that acts like multiple amplifiers with the required speed. There were two separate attempts to pursue such an architecture but to the author's best knowledge no actual detector has been produced from either efforts. The efforts themselves are in a state of long hiatus if not abandoned.

3.1.3 Low order NGS wavefront sensors

The LGS wavefront sensors filter tip-tilt and other quadratic blind modes completely. There are also some modes that are not fully estimated from the LGS wavefront sensors measurements [5]. The blind and null modes are Kolmogorov in nature and with two TT and one TTFA sensor can give us this missing information at atmospheric time scales for the most part.

To achieve the sky coverage as specified by the SRD, the TT(FA) sensors are infra-red that work on a diffraction limited core and have dedicated MEMS mirrors on each channel to sharpen field TT stars. The IR TT(FA) sensors are susceptible to sky background and so it is necessary to find a optimal size field stop. A f/15 beam with a HgCdTe's 18 μm pixels yields a 30 masec/pixel native plate scale at the detector, which is same as the spot size by pure coincidence. Sky background is a big issue at J and H bands. To keep the sky background under control and still have the correct centroiding accuracy and dynamic range it is imperative to adopt the right plate scale at the detector. One could envision a adjustable field stop to take care of sky but it has to be positioned after the MEMS DM (and hence arises the need for creating 2 foci after the DM). Alternately one could cut on sky by doing the same thing electronically. A *Bravais lens* could be employed for guiding on partly resolved planet-like objects with increased field of view. The suggested field of view is 30 masec. A Bravais lens could possibly increase the FoV to 150 maSec.

The IR sensors will do for serving as TTFA sensors since the number of active pixels is small and hence can be read out at atmospheric time-scales.

References

[1] M. Britton, R. Dekany, NGAO Performance Budget Summary, Keck Adaptive Optics Note,491

[2] B. Bauman, Private Communication

[3] B. Bauman, D. Gavel and R. Kupke, `http://www.oir.caltech.edu/twiki_oir/bin/view.cgi/Keck/NGAO/AOSystemDesign`

[4] Wizinowich, Radau, Keck Adaptive Optics Note No. 137, Wavefront Sensor Optical Design.

WFS type	**Location**	**Sensing band** [FWHM nm]	**Input PS(μm/")**	**# of sub-ap**	**Detector PS(μm/")**	**Detector pixel** size [μm]	**Comment**
LGS HOWFS	after 2^{nd} relay	400-900	2254.38	32x32 32x32	1.5	13	OSM needs to be figured out
LGS HOWFS	after 1^{st} relay	589	727.22	64x64 32x32 16x16	1.45	13	Look at Tech. challenges
TT	inside d-NIRI after 1^{st} relay	1159-1778	727.22	1x1	0.03015 (150)	18	d-NIRI OSM MEMS correction
TTFA	inside d-NIRI after 1^{st} relay	1159-1778	727.22	2x2	0.03015 (150)	18	d-NIRI OSM MEMS correction
Truth Sensor	after 2^{nd} relay	400-900	2254.38	5x5	1.6	13	do we need one more at d-NIRI

Table 2: Design input parameters for NGAO WFSs [6]

[5] R. Flicker, C. Neyman, Keck Adaptive Optics Note (KAON) 492: Null-modes and quadratic mode tomography error in LGS-based multi-beacon tomography AO systems.

[6] A. J. Pickles, `http://www.astro.caltech.edu/~pick/Pal_basic.html`

[7] R. Smith, Private communication.

[8] ESO Documentation, `http://www.ls.eso.org/lasilla/sciops/3p6/adonis/html/ircameras.html`

[9] G. Finger et. al., Performance limitations of small format high speed infrared arrays for active control loops in interferometry and adaptive optics, `http://www.eso.org/~gfinger/Glasgow_2004/gert_finger_picnic_5499-32.pdf`

[10] R. Dekany et. al., NGAO Error Budget Spread Sheet Version 1.26.