



KAON 558
Dithering and offsetting with NGAO:
possible designs

David Le Mignant, Christopher Neyman¹
 W. M. Keck Observatory,
 March 11, 2008

1. Introduction

This document presents and briefly discuss new possible conceptual designs for dithering and offsetting with NGAO. The implementation for dithers and offsets with the current Keck AO systems present severe drawback in observing efficiency and positioning accuracy. NGAO presents a flexible design that would allow for much more efficient dither and offsets.

1.1. Why care about dither and offset for NGAO?

The design implemented for the Keck AO system in NGS and LGS mode includes a back-and-forth serial communication between the telescope drive control system (DCS), its pointing control (PNT), the AO supervisory control (SC) and the AO optics bench motion control software (OBS) and leads to significant overheads that are summarized in the following table:

AO modes	Subsystems involved	Dither: 0 – 3 arcsecond	Offset: 5 – 30 arcsecond
NGS	Telescope – AO FSMs	5-10 seconds	5 – 15 seconds
LGS – laser on-pixel	Telescope – AO TSS	3- 8 seconds	5 – 15 seconds
LGS – laser follows-star	Telescope – AO TSS – AO FSMs	5-10 seconds	10 – 25 seconds

Table 1: Dither and offsets with the current Keck AO systems.
 TSS: tip-tilt sensor stage where the STRAP TT unit is mounted;
 FSM: field steering mirror feeding the high order WFS.
 For laser “on-pixel” or “follows-star” – see definitions below.

In addition the NGS repositioning accuracy on the science array is in order of 20 milli-arcsec rms for a dither amplitude of less than 3 arcsec. The peak error can reach 50 mas. The TSS repositioning accuracy is less than 10 milli-arcsec, as measured on the focal plane. The telescope pointing accuracy is not a factor in this positioning accuracy.

We would like to be more careful in our NGAO design and propose a design that minimizes overhead while maximizing operation flexibility and repositioning accuracy.

1.2. Definitions

We propose the following definitions in this document:

- **Dither:** for Keck AO, a dither is defined as a repositioning of the field on the science array of less than the size of the science field of view, typically less than a few arcseconds in amplitude, less or comparable with the seeing size and less than a few hundred pixels on the science array. Yet, this definition assumes small field of views for the science camera and leads to confusion when the science instruments have very different field of views. Therefore, we propose this new definition for NGAO: by definition, a dither is defined as a repositioning of the field on the science array that does not require any telescope offset nor pausing the Low Order WFS (LOWFS) loop. The small amplitude allow the NGAO system to handle the move by dithering internal optics. LOWFS/TWFS (truth WFS) and high order (HO) AO loops are not interrupted and remain closed at all times.
- **Offset:** for Keck AO, an offset is defined as a telescope move of a size that is comparable or greater than the science field of. Again, the same confusion may arise with NGAO, and we would like to propose: an offset requires the telescope to move and the LOWFS to pause and resume closed loop operations. All LOWFS and TWFS AO loops will pause and resume, while telescope and AO will reposition for the new demanded position. HO loops may pause and resume if required to reposition the LGS. Note that there is no need to open the UTT, HO loops or the laser pointing compensation loops while the telescope position is being adjusted as the LGS moves with the telescope. Actions are commanded in parallel as much as it is possible to minimize overhead.
- **Laser on-pixel:** a laser spot is said to be “on-pixel” when its position on the sky changes as the telescope is re-positioned. In other words, the laser changes its position on the sky with respect to the science object, but the position of the laser with respect to a pixel detector remains fixed.

¹ with comments and inputs from P. Wizinowich and A. Moore.



- Laser follows-star: a laser spot is said to “follow-star” when its position on the sky does not change (e.g., requiring the LGS steering mechanism to the WFS to move) as the telescope is re-positioned. In other words, the laser is not changing its position on the sky with respect to the science objects. The point-and-shoot lasers used for the NGS may have to be steered to remain superimposed to the NGS.
- Additional laser configuration: note, technically, there a third situation (never used with Keck II LGS AO) where the laser changes its position on the sky and with respect to the science detector, requiring the LGS steering mechanism to the WFS to move.

2. Working on a new dithering paradigm for Keck NGAO

In this section, we would like to propose a simple conceptual design for fast and accurate dither. A more detailed study will be required for the implementation.

2.1. Dither by steering the science light path only

One can imagine steering the light beam on and around the science array with high accuracy using a steering mirror or a probe arm installed in the science light path. Any move can be very fast (very likely < 2 sec), and the steering mirror could be used for fine guidance/centering on a slit, a spaxel, a coronagraphic spot or any location on a detector. This steering mechanism could be used to compensate for differential atmospheric refraction, differential tracking, or any effect leading to centering and positioning error on the science path. The AO loops would remain closed as long as required on the LOWFS, the high order WFS, etc.

2.1.1. For the d-IFS:

In the current NGAO design, this can easily be implemented for the d-IFS by steering 1) the probe arms and/or 2) the MEMS. The maximum amplitude for a probe arm will depend on the distribution of the probes, and which part of the total field each probe can access without interfering with the other probes. The maximum amplitude for tip and tilt on MEMS would have to be quantified: The d-IFS are supposed to have 1x3” fields. So, presumably the d-IFS MEMS tilt would be up to ~2”. This requires that the d-IFS optics in front of the MEMS simultaneously transmit both the original field and the dithered field. The LOWFS and the truth sensor would not have to pause close loop operations as long as the dithers remain within the amplitude allowed by the MEMS. This would allow for more flexibility for the d-IFS including different individual or total integration time per unit (e.g, one unit may be used for PSF monitoring). Steering the pupil would not cause any problem downstream in the science instrument since the MEMs are at the pupil.

2.1.2. For the narrow-field science instruments:

The situation would be similar for the narrow field science relay: the narrow field DM is mounted on a tip-tilt mount that allows steering the beam around. Such a design is being implemented at the NRL (see <http://rsd-www.nrl.navy.mil/7210/7216/ttoko.htm>). There is potential risk for the resonant frequency of the TT mount, but we would only use this steering at low frequency. The TT correction would still be applied using the woofer stage.²

This should not create any problem for the NGS HO WFS or TWFS. Once again, many observing actions related to fine acquisition/ fine centering and dithering become easier and faster.

Here again, steering the pupil would not cause any problem downstream in the science instrument as the tweeter will be located at the pupil. Yet, steering the pupil around could potentially lead to spatial variations in the background emission (as light hit different part of the optics at each dither step). This could be detrimental for observations of faint extended objects at longer wavelength than H. We need to understand the requirements for these variations. Note that these spatial variations are likely to be temporally slow and one could imagine a dither/chop observing scenarios (as it is done in the thermal IR) to calibrate for it and subtract it out.

The beam for the visible and NIR camera and OSIRIS would be steered all at once, leading to no-added flexibility in case of simultaneous visible/NIR/OSIRIS science operations.

This dither scenario process cannot be implemented as it for NGAO in NGS mode since the NGS WFS is operated in closed loop mode. A counter-chop will be necessary for the NGS mode as explained in the next section.

² Note from PW: Both the woofer and tweeter will be mounted on TT stages. The interaction between the DM and TT is more of a concern for the woofer due to the mass of this DM. I suspect that we will not be able to drive the woofer TT at as high a level of performance as the tweeter TT. Presumably we will apply TT at the highest bandwidth to all the TT MEMS and at a somewhat lower bandwidth to the woofer TT.



2.2. Dither by steering the common light path with counter-chopping on the WFS (LOWFS/TWFS/HO WFS):

Another possible, yet less attractive, solution would consist of steering the beam in the common light path (e.g., using the woofer unit). The woofer unit would need a large amplitude (greater than 5 arcsec). The LOWFS pick arms or the MEMS could then be used to counter-chop the NGS on the LOWFS/TWFS. It is uncertain whether this dither mode requires to pause and resume the operations for the LOWFS/TWFS loops. The LGS would need (resp. not) to be repositioned on the HO WFS in the “laser follows star” (resp. “laser on-pixel”) mode.

The science objects on d-IFS would be dithered all at once, which leads to less flexibility for the science operations. The same scenario apply to the narrow field science.

A similar counter-chopping process can possibly be implemented for NGAO in NGS mode.

3. Offsetting with NGAO

Offsetting requires sending a move command to the telescope either in instrument (pixel) or telescope (ra, dec or el, az) coordinates. It also requires repositioning the steering mechanism for the AO sensors.

For NGAO, offsetting would be used for recording “blank” sky on the detectors, acquiring a different set of galaxies on the d-IFS, or making large amplitude dithers on the 30” field-of-view NIR camera in both LGS and NGS modes.

The offsetting scenario requires pausing, repositioning and resuming the AO loop operations. The positioning accuracy, constrained by the steering mechanism in LGS and NGS mode, and the total overhead are the most important requirements in the implementation of the integrated offset command.