Vibration characterization and mitigation at the Gemini-South telescope

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Abstract

This work presents the first results obtained when testing different types of controllers for GeMS Tip-Tilt mirror loop. Two new controllers, Kalman and H_∞ have been compared to the standard integrator. Results show excellent vibration rejection features for the first two cases.

GeMS

The main characteristics of the GeMS system [1] are :

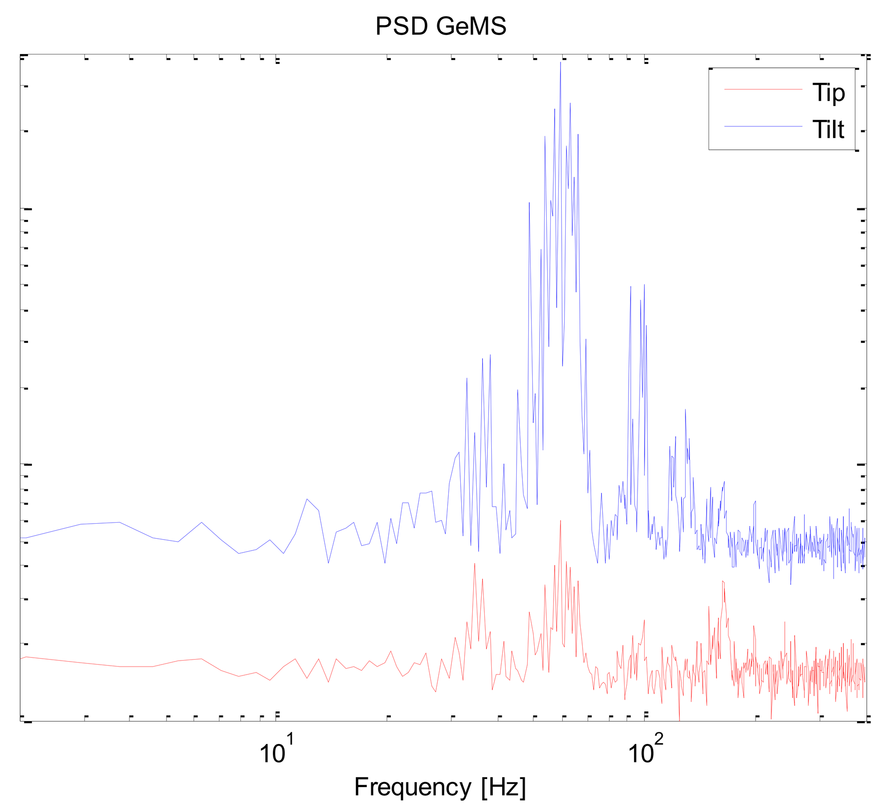
CANOPUS:
- 5 LGS WFS 16x16 Shack-Hartmann
- 3 DMs totaling ~800 actuators, conjugated to 0, 4.5 and 9 km ranges
- 3 APD based NGS Tip-Tilt WFS
- 1 NGS slow focus WFS

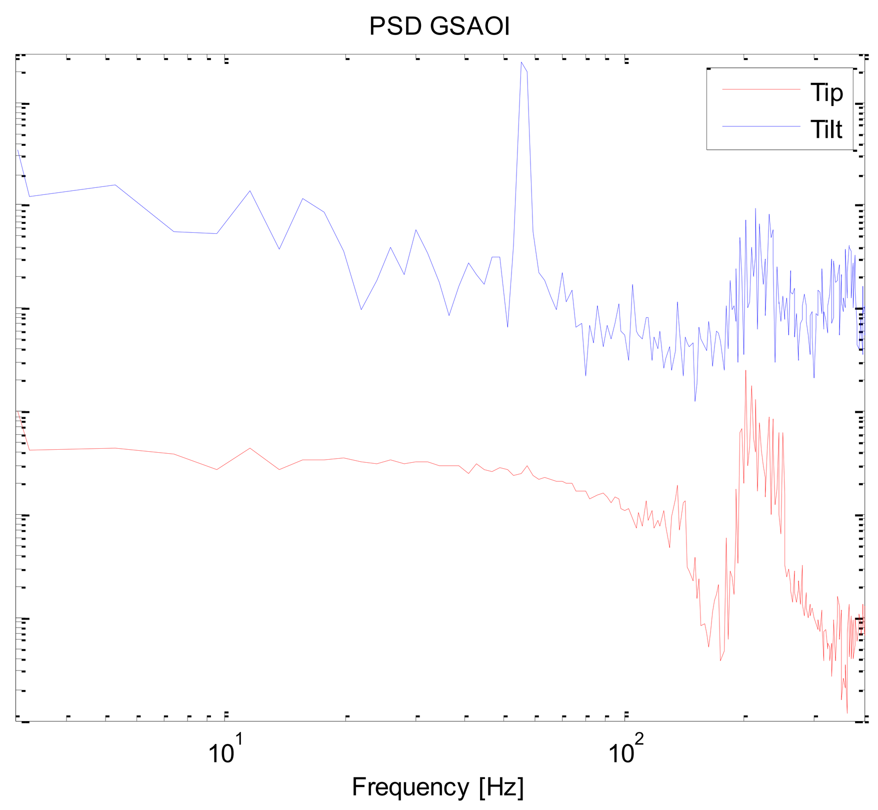
- 1x50W laser divided in 5x10W beams placed on the corners and center of a 1'FoV

The goal is to reduce the vibrations associated to the Tip-Tilt Mirror loops that eventually affect the IR image quality of the scientific camera (GSAOI).

Diagnosis

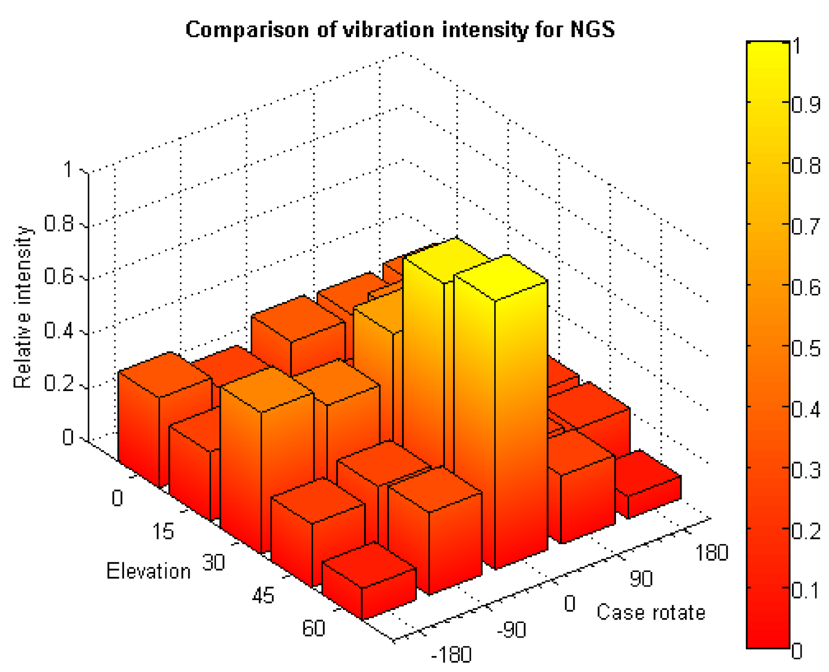
The figure shows the Power Spectral Density (PSD) for the Tip and Tilt loop residuals and GSAOI centroids, obtained from ODGW (6x6). The Tip value has been displaced vertically for better visualization.





A strong vibration band around 55Hz can be seen in the Tilt direction for both instruments, meaning that the perturbation is in the common path.

After identifying the 55 Hz peak, a characterization of this perturbation was carried out for different case rotations and elevation values. The right figure shows a 3D plot where elevation seems to be a more relevant variable than rotation.

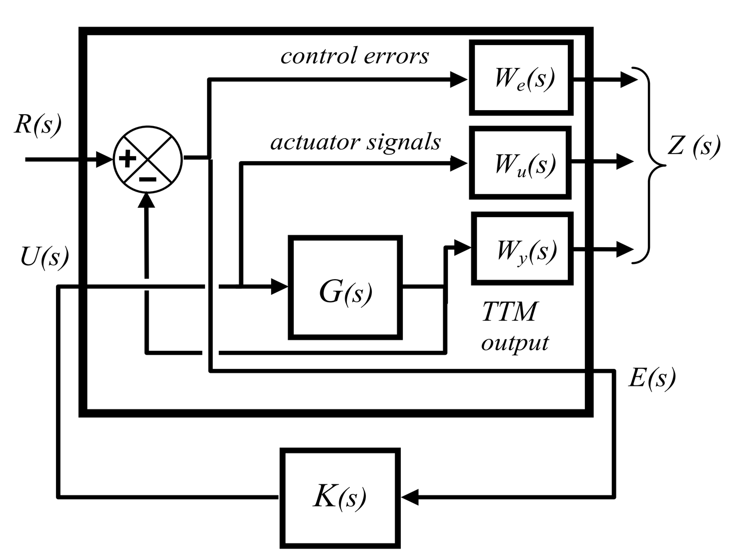


Controllers

Two types fo controllers were tested in order to mitigate this effect, namely Kalman and H_∞ . A detailed description of the Kalman approach can be found in [2]. In the H_∞ approach, the technique finds the optimal controller by minimizing the norm:

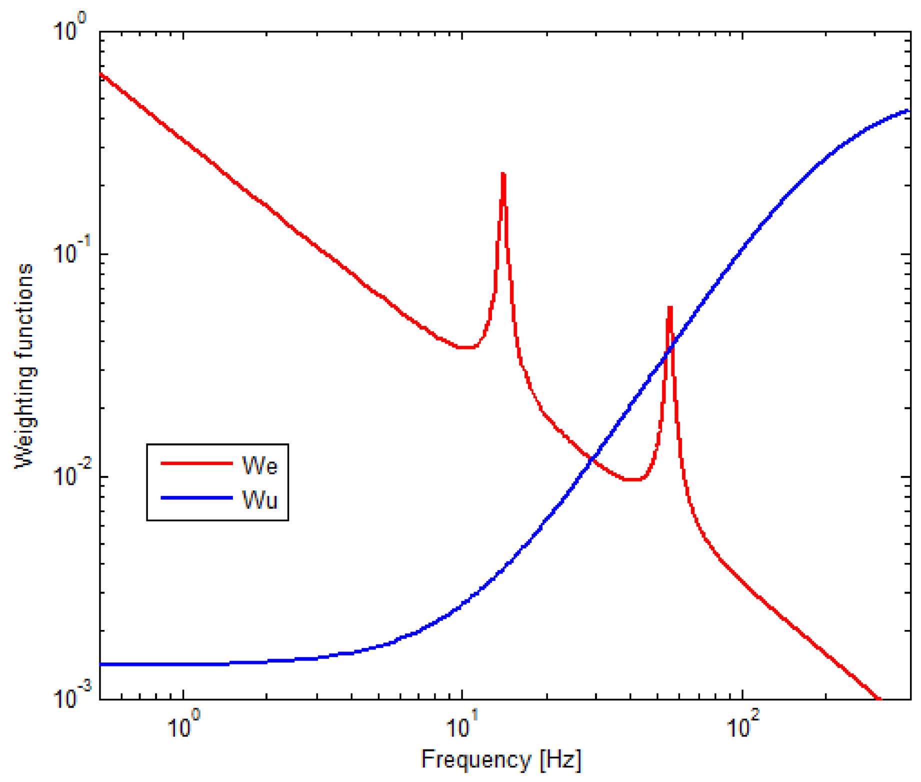
$$\min_{K(s)} \|Z(s)\|_\infty = \min_{K(s)} \left\| \begin{matrix} W_e\, S \\ W_u\, S_u \\ W_y\, T \end{matrix} \right\|_\infty$$

where Z is constructed out of the augmented control configuration [3]:



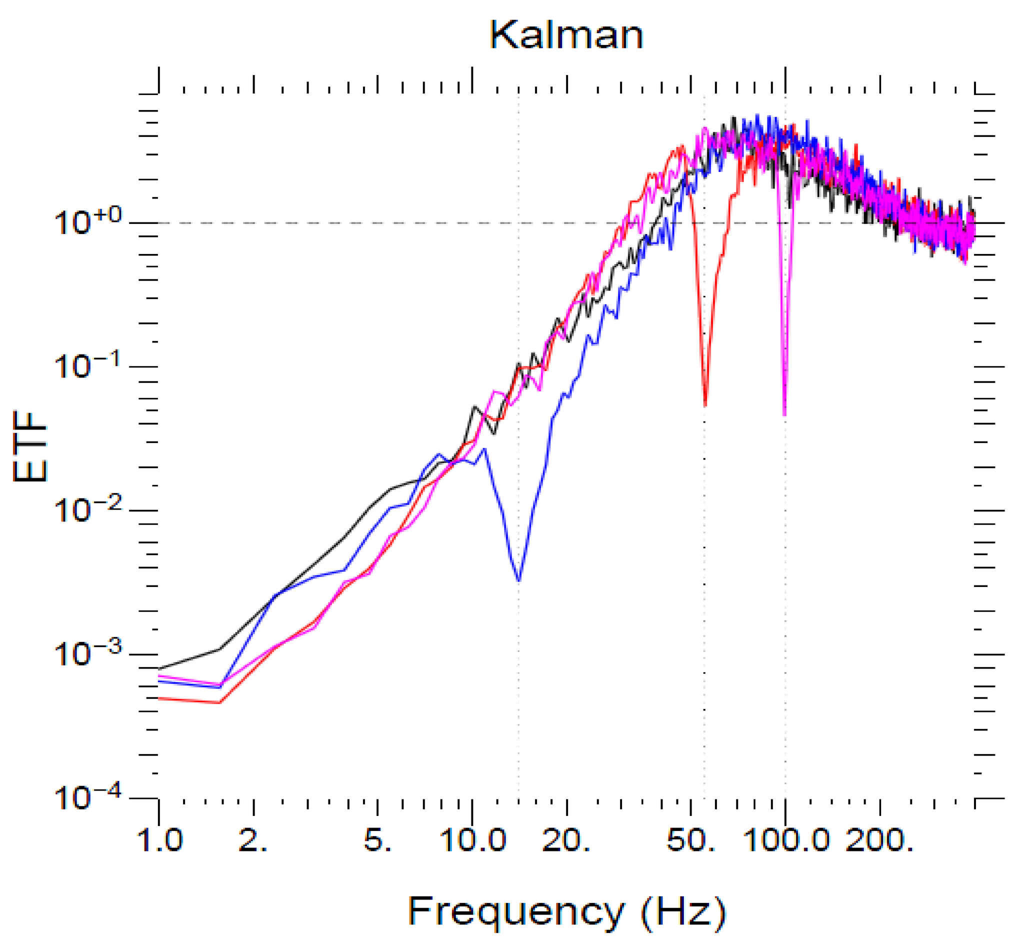
Weighting functions $W_e(s)$, $W_y(s)$ and $W_u(s)$ contains performance requirements sought for inputs and outputs, and they also offer a solution when trying to obtain contradictory objectives such as small servo errors and actuator range limits.

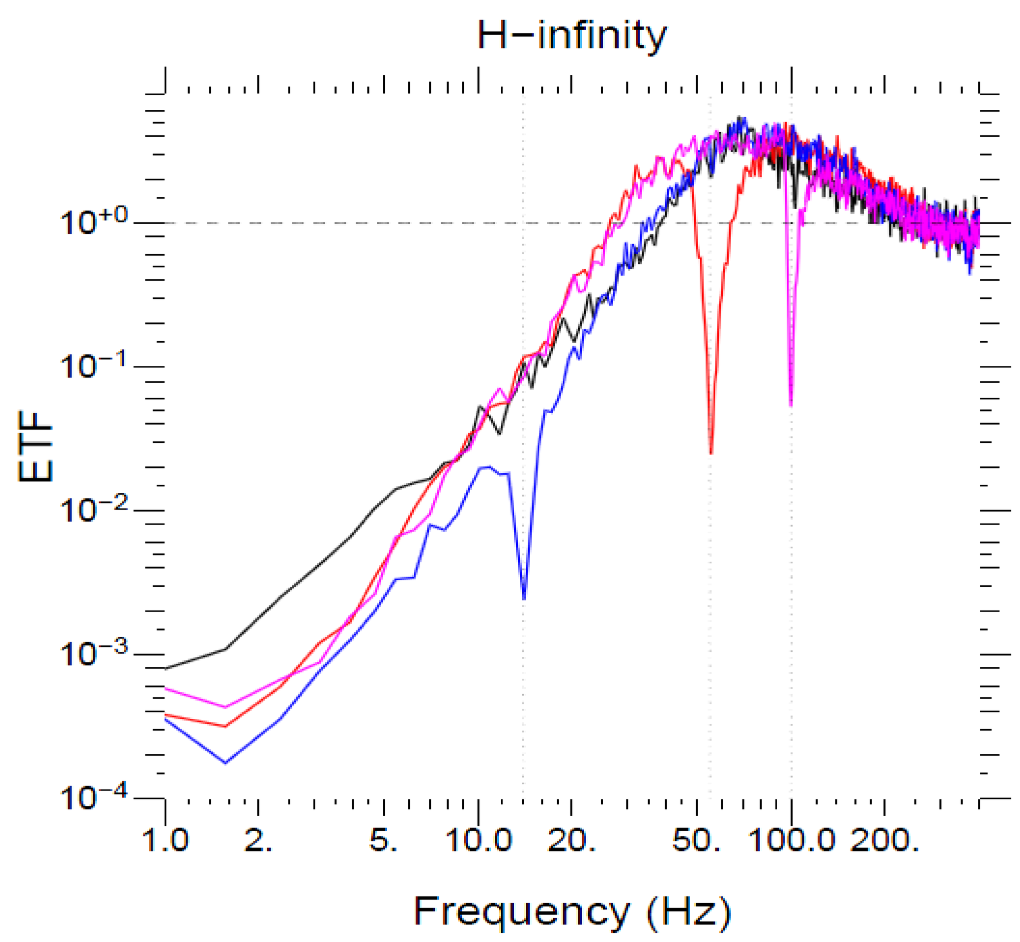
The next figure shows the $W_e(s)$ weighting function for the case where two vibrations at 14 and 55 Hz are sought to be eliminated. Function $W_u(s)$ penalizes the use of control energy at high frequencies.



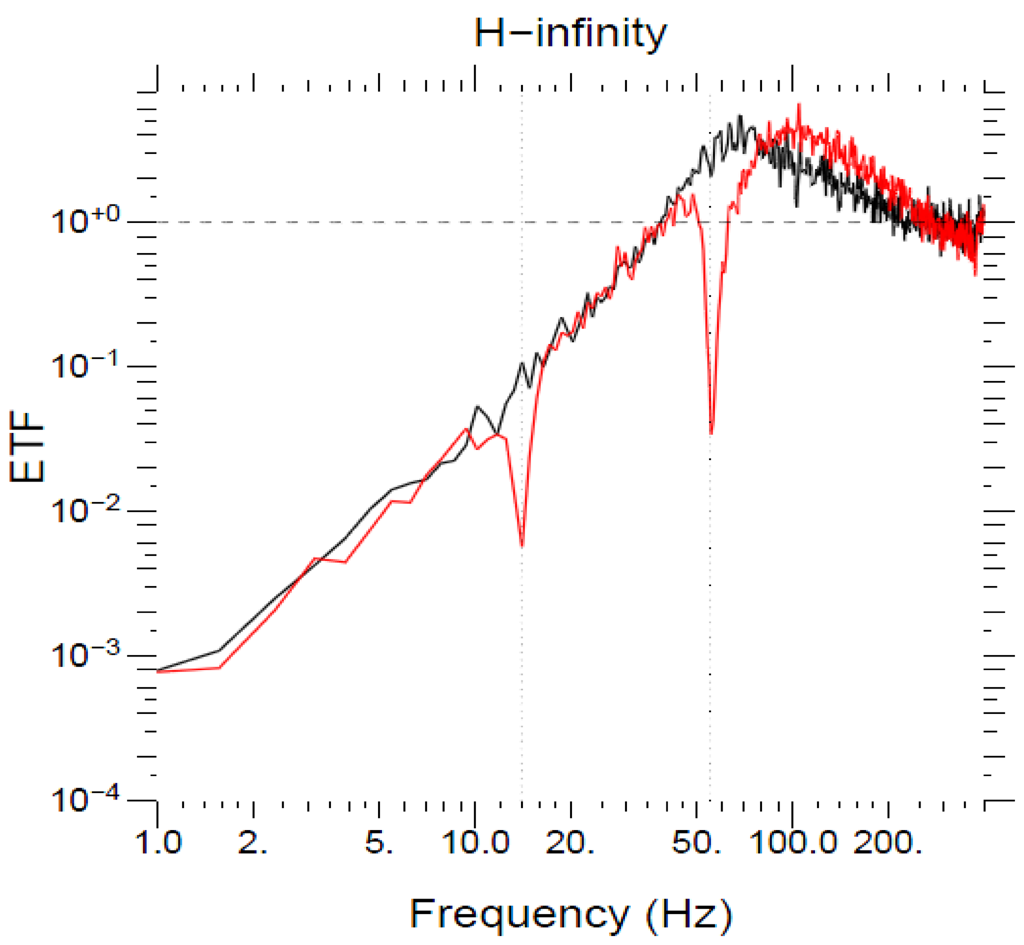
Results

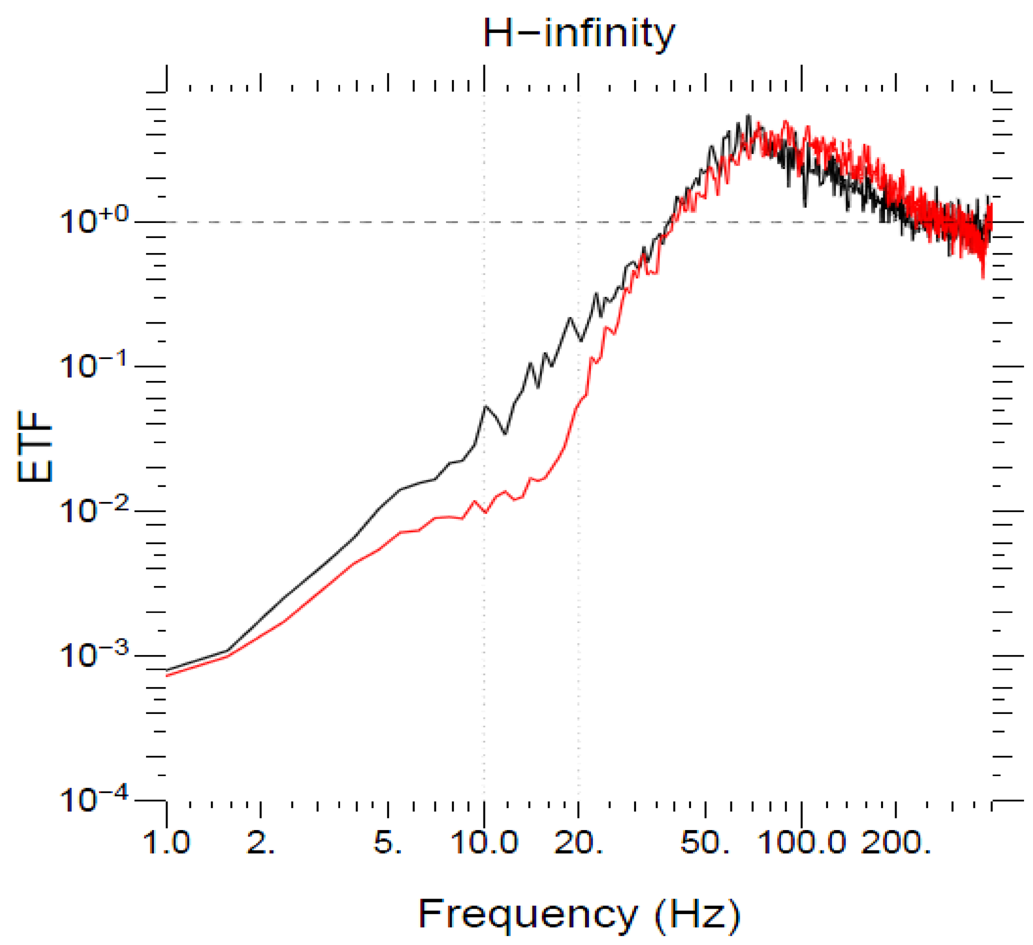
The next two figures show experimental Error Transfer Functions (ETF) for Kalman and H_∞ controllers aimed to reject vibration frequencies of 14Hz, 55Hz and 100 Hz. The black curve corresponds to the classical integrator controller with gain of 0.4. The results are similar for the advanced techniques that effectively attenuate these singularities. They also have a better response at lower frequencies, but higher errors at medium frequencies due to the Bode theorem. The calibration was made to get equivalent overshoot values for the three controllers.





Among the nice features of the H_∞ approach are the easy inclusion of mirror dynamics in the optimization process and a straightforward definition of ETF shape by using the previous weighting functions. An example of the latter are presented in the following figures, with two vibration being rejected simultaneously (left) and also an attenuation of a specific frequency band between 10 and 20 Hz (right).





The next table presents residual RMS values obtained for the three controllers under three turbulence conditions: i) Case I: Slow wind and strong 55hz vibration; ii) Case II: Turbulence that matches the 1/ETF response of the advance controllers, computed using a white noise turbulence; iii) Case III: High wind and weak vibration at 55 Hz

Turbulence / Controller	Case I (Tip/Tilt)	Case II (Tip/Tilt)	Case III (Tip/Tilt)
Open-Loop	86.5 / 48.4	88.1 / 44.2	52.1 / 71.9
Integrator	20.2 / 20.2	15.9 / 7.1	32.5 / 29.4
Kalman	8.6 / 6.0	13.1 / 6.7	26.4 / 31.1
H_∞	4.8 / 6.1	11.9 / 6.3	27.1 / 30.0

Results show significant gains for Kalman and H_∞ controllers when turbulence is weak or when it matches the controllers' response. For faster turbulence (higher winds) this advantage vanishes, mainly due to the servo loop bandwidth.

Conclusions

First results are very encouraging and demonstrate that we are able to filter and adjust the rejection at GeMS instruments.
The above results show the necessity of identifying the turbulence characteristics on-line, so as to use a well tuned controller for better results.

References
[1] F. Rigaut, B. Neichel et al., "First on-sky results for GeMS", Adaptive Optics: methods, analysis and applications (AO), Toronto, Canada(2011)
[2] K.J. Astrom, "Introduction to Stochastic Control Theory", Academic Press, (1970)
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