

# Open-loop Biased-noise Responses of the MMT Azimuth Axis

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## Introduction

During last June's data collection campaign, open-loop measurements were taken of the MMT absolute encoder and motor encoder position outputs when the motor amplifiers were driven by a sinusoidal chirp signal. In this report, one data set is presented for different elevation angles, all scaled to telescope position units of arcseconds. The biased pink-noise source and encoder outputs are sampled at 50Hz, while comparison data from the chirp response measurements are sampled at 500Hz.

This set of open-loop measurements were taken using biased pink noise as suggested by Gawronski in his work on radio telescope controllers; while a potentially accurate and useful method of collecting data for system identification, it falls somewhat short in this particular run of testing, as we will see.

## The Data

For this report, I present only one test result in the interest of time and space. It is fairly representative of the rest of the noise-response data sets, and clearly shows the deficiencies (discussed later) in the data collection.

All the above data arrays are from the file: *open\_loop3.mat* in my data archive, available at the URL <http://www.mmt.org/~dclark/AzimuthTesting/> for interested parties. The input signal is chosen to be a band-limited ("pink") noise source with an adjustable bias set large enough to just overcome the starting friction of the azimuth drivetrain. In this way, slow motion is maintained throughout the test, making friction more or less constant and minimizing the low-speed nonlinearities in the encoder output data. The input signal is clipped to prevent large excursions that may damage the telescope, as well.

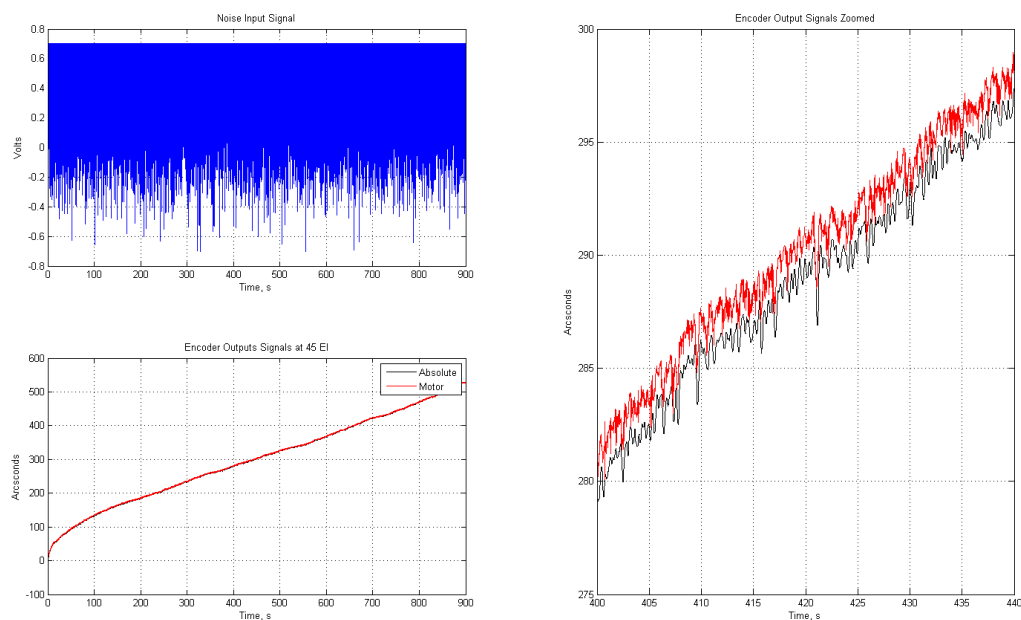


Figure 1. Input-output Data for Pink-noise Testing

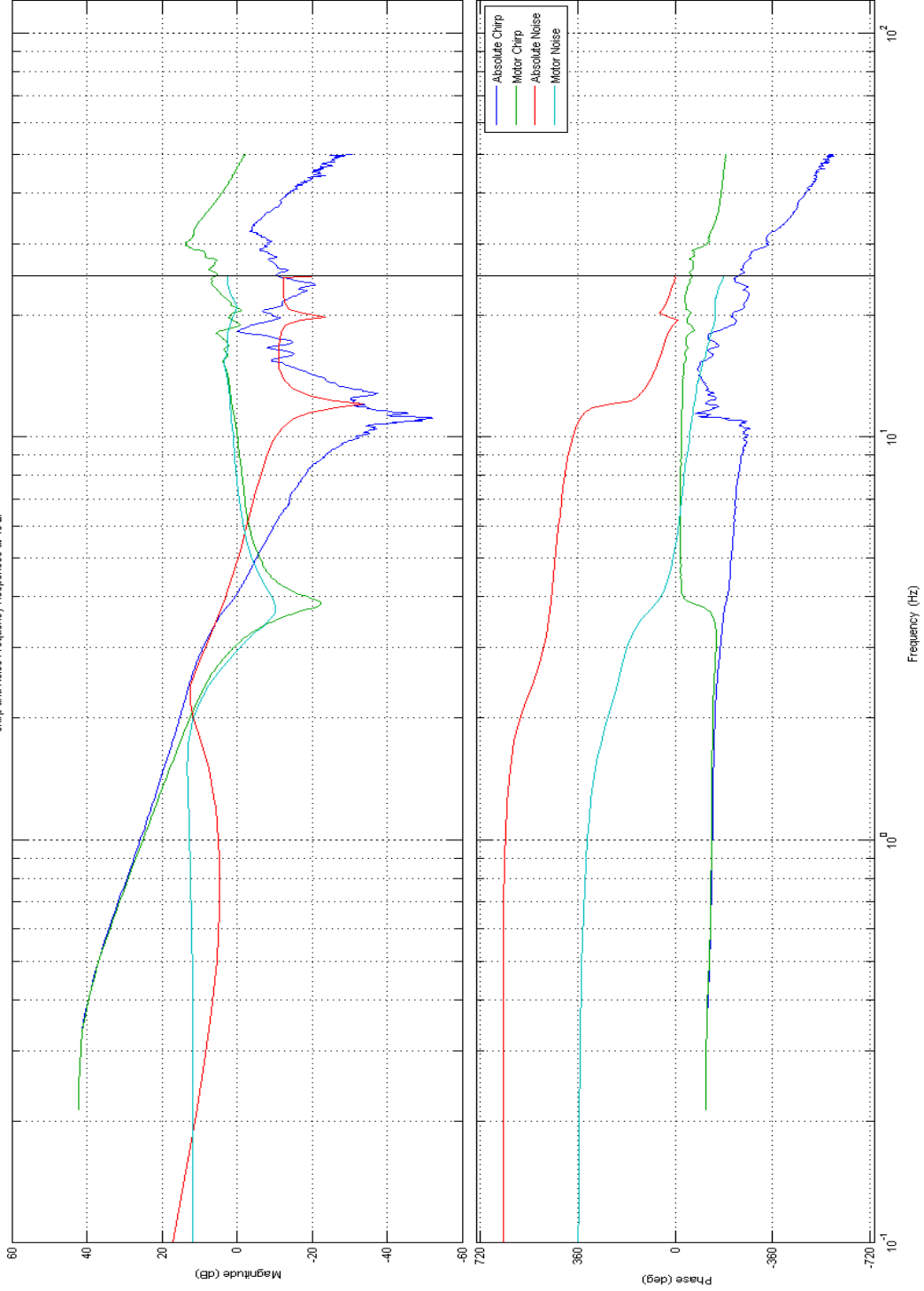
As can be seen, the azimuth axis is moving slowly for the duration of the test, about 0.5"/s. The noise data show that the encoder output variation is of order 5" peak to peak. It turns out, this is far too gentle to overcome the friction nonlinearities in the drive system; the output data is distorted a great deal by the drive system nonlinearities and make reduction of the input-output data to accurate models a difficult proposition. I am reluctant to try less gentle testing due to the potential for large, fast torque transitions to damage the drive system gearing; more careful input-signal choices need to be made before I try this method again.

On the following page, we have an overlay of the Bode plots from the earlier chirp response data collected at 45° elevation, with the data from the noise response measured at the same position. The noise data were reduced using the Matlab System Identification Toolbox. The encoder signals were both scaled to arcseconds, mean offset subtracted and detrended. The PEM (prediction-error) method was used to create 8<sup>th</sup>-order state-space models of the input-output data, with the initial states estimated by backcasting. The *ident* toolbox makes many other numerical methods available for massaging the data and creating "black box" models. For this, I choose only to try the simplest, most straight-forward of these tools. We've had excellent results in the past with the elevation axis using chirp-response data carefully matched to hand-generated models; I anticipate continuing with this method, although I wish to refine the noise-response approach since it has the potential to much more accurately identify system characteristics not necessarily captured during a swept-sine test – in part since a chirp-response test only provides responses with the range of input frequencies applied, and only with the resolution of the chirp frequency step size.

The *ident* tool outputs definitely show that the data collection method with noise, compared to chirp testing, is far less accurate. First, since the sample rate is only 50Hz, the Nyquist limit is lower than the higher-frequency modal shapes seen in the chirp-response data. Next, the noise input signal was fairly small, and so contained relatively little power in the low-frequency range below about 2Hz. Clearly, the identified model and the chirp response diverge greatly in the lower range of the Bode plot. Also, there was not nearly enough dwell time, or energy, near the modal frequency range of interest from 10 to 30Hz. The identification output clearly shows a double peak as we might expect, but has the center frequencies and damping off by a considerable amount. We also see that the identified phase is wrong, also. What *is* good about the identification method is that it is a powerful way of getting good, smooth models of the system from fairly noisy data. This, coupled with good data sets, points the way to a more automated approach for model development that will be useful in the future.

See the next page for the details of the frequency response:

Chirp and Noise Frequency Responses at 45 EI



**Conclusion**

The data shown here make it plain that data collection with pink-noise sources is an art that requires good judgement on the part of the control engineer. I will be looking at the gearbox ratings to produce an ultimate do-not-exceed limit on input torques and torque rates to ensure we never test with something dangerous. I'm encouraged that smooth system models can be obtained from identification data. For future testing, I believe that on-line data quality assessment should be part of the effort, since waiting months to reduce the data (as was necessary due to the aluminization effort) makes things much more difficult than necessary. The next round of testing should include enough time in the request to do at least some "quick-look" checking to make testing as efficient as possible.