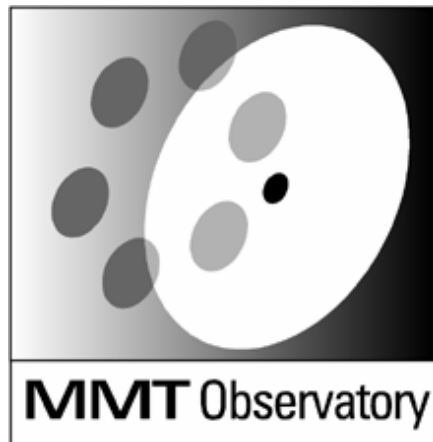


MMTO Internal Technical Memorandum #03-5



Smithsonian Institution &
The University of Arizona®

Selected Results of Recent MMT Servo Testing

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July 2003

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Abstract: *The methodology and results of testing the MMT azimuth and elevation servo drives during the week of July 9 - 12, 2003 are presented with transfer functions and PSD plots showing the current servo behavior when a disturbance signal is applied to the servo loops. Hardware and software tuning changes introduced during the testing are shown in comparison to the prior state of the servo.*

Introduction

During M&E time scheduled in early July 2003, a number of characterization tests were done on the MMT azimuth and elevation drive servo systems to develop a better understanding of the servo behavior during operation. The input/output data were generally of the form of disturbance rejection measurements captured with an HP 35670A Dynamic Signal Analyzer (DSA) using its internal swept-sine source output. Some additional data were obtained with a pink noise source (i.e., band-limited random noise with a zero mean). Output data were gathered from: an accelerometer mounted in various locations on the telescope, motor encoders, tape encoders, and the servo command signals driving the axis under test. Additional data were taken from the mount control VME computer, which has a “snapshot” utility for gathering servo loop data. These data are archived on the MMTO main server at [mmto://home/dclark/MMT Servo Data/Servo Testing 7_6-12_03](http://mmto://home/dclark/MMT_Servo_Data/Servo_Testing_7_6-12_03). They will be made available to interested parties on request. For the purposes of this report and to prevent repetition, only a selected number of particularly illustrative results are presented due to the large number of files and test conditions.

Servo Test Methods

For developing a disturbance rejection test on the servos, the DSA swept-sine source was used and summed into the DAC output to the servo amplifiers using a non-inverting summing circuit. The output response was selected to be either the encoder output or the servo command into the summing junction. The quality of this method can be very high, since the DSA automatically correlates its input/output channels when running a swept-sine test. In addition, the frequency points were generally set to 0.05Hz resolution, giving excellent resolution at lower frequencies, although this tends to fall apart at higher frequencies due to the lowered dwell-time at a particular test frequency and the resultant inability of the system to stabilize during the measurement period. This test method was further validated by applying a pink noise source to the summing junction and measuring the same output(s). This gave good general agreement at low-to-mid frequencies with the swept-sine measurement; the caveat here is that the noise source tended not to be perfectly “rich” in frequencies in the test frequency range, so overall frequency resolution tended to be lower compared to the swept-sine method.

For capturing the incremental encoder outputs and passing them to the DSA, which expects analog signals, an ARCs Lightning DSP board was used to read the encoder and convert the encoder position to an analog value via the on-board 12-bit DAC. A tunable variable was used to set the DAC scaling, which was generally set to 0.1V/arcsecond. The noise source was likewise developed

by the ARCs board using a compiled pink noise source developed with MatLab block sections. These ARCs utilities are also available to those interested upon request.

Capture of the accelerometer outputs was easily done by direct connection of the accelerometer charge amplifier to the DSA input channel. While these tests are not presented here, the reader should be aware these data exist, should the need to analyze this information arise.

Servo “snapshots” contain useful data: the current absolute and incremental encoder values, the position error, and the velocity demand output by the outer position loop to the LM628 velocity loop controller taken at every outer loop servo tick (100Hz). These data are buffered in the VME computer memory (up to 4000 points) and written over a network socket to a file on a remote computer. This is a convenient method of data gathering that guarantees lossless collection.

Test Results

Refer to the attached figures for viewing the test results discussed below:

Swept-Sine Disturbance Rejection Tests

The transfer function shown in Figure 1 displays the input/output relationship of a disturbance input to the elevation tape head position output. System modeling carried out by D. McKenna (SO) suggested that an improvement in the system performance could be obtained by converting the elevation servo amplifiers from a current-source to a voltage-source mode. The ideal result of this type of test is a gain plot at $-\infty$ gain and 180° phase.

We note that there is indeed disturbance suppression at frequencies below about 1Hz, but the phase is not 180° as expected. The encoder feedback may also in reality be the inverse of that shown due to a reversal of the quadrature signal lines.

Also of interest on this plot is the complete lack of change to the resonant mode pairs at 5 and 6Hz, along with 13 and 18Hz. We can conclude that these appear to be structural resonance modes. Of even greater interest is the phase relationship obtained in the two tests: changing over to voltage-source mode improved the phase linear region by 0.8Hz. As might be expected, the rapid phase shift at ~ 2 Hz introduces a gain peak as well.

The transfer function in Figure 2 presents the relationship between the disturbance input and the LM628 velocity-loop controller output. The ideal result would have exactly 0db gain and 180° phase, indicating perfect suppression of the disturbance signal.

The actual output shows a less than 0db gain and a phase shift of less than 180° . Clearly, the disturbance is *not* being suppressed, even at very low frequencies. Again, we have the increase in phase linearity of 0.8Hz and the concomitant shift in the peak magnitude. Indeed, the output is in phase with the disturbance at above ~ 2.5 Hz! With this behavior, it is easy to understand why wind rejection of the elevation axis is so poor. Although the disturbance rejection is far from perfect, it *was* improved by the change in amplifier modes.

Figure 3 presents a transfer function for the azimuth motor encoder position before and after a tuning session in an attempt to improve the wind rejection, which had been reported by MMT

operators to be degraded. A scaling difference in the encoder to analog conversion utility of 10X is responsible for the magnitude differential between the two. The frequency notch is the familiar (known since the 1980s) gearbox compliance mode. Again, we have the imperfect phase and magnitude relationship seen in elevation. The new tuning did have a small salutary effect on the phase at frequencies below ~ 0.2 Hz. We can again conclude that disturbance suppression is fairly hopeless at low frequencies.

The LM628 disturbance transfer function is shown in Figure 4. The azimuth servo loop clearly does not have sufficient gain to even approach the 0db level, and the phase is mysteriously around 90° . While tuning helped this a small amount, it's probably not enough to give good results in the face of wind disturbances.

Servo Data Snapshots

After setting up the elevation amplifiers and re-tuning both axes, the telescope was pointed into and out of a fairly high wind to gain some data on the frequencies present during actual operation. While several runs were taken, the worst-case tracking conditions are shown in the last two figures. For elevation, this means pointing directly into the wind, and for azimuth, this is at 45° to the wind.

Figure 5 was taken by detrending the absolute encoder and tape head encoder values and converting the values from encoder counts to arcseconds on the telescope axis. The PSD is therefore the power spectrum in arcseconds. The Steward CAAO group had previously reported anomalous frequencies in their high-speed image data, which indeed show up on the tape head output, but *not* the absolute encoder, although the two generally agree at other frequencies.

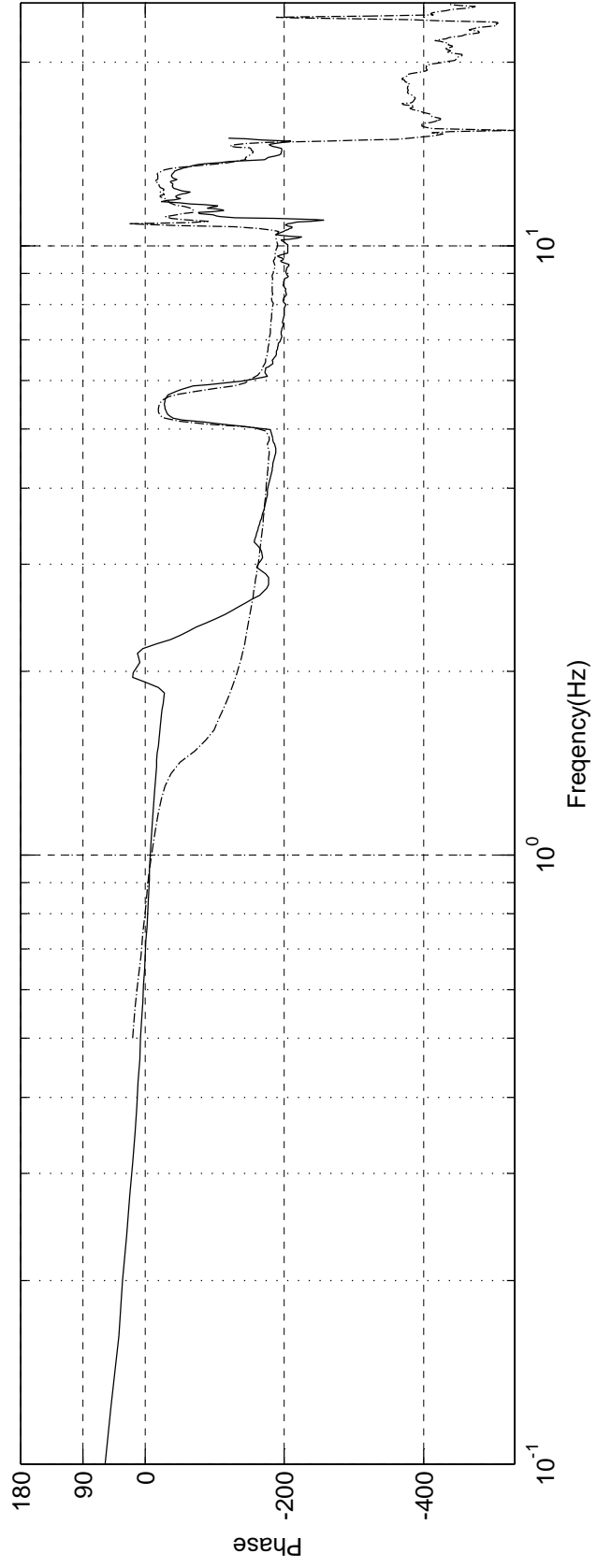
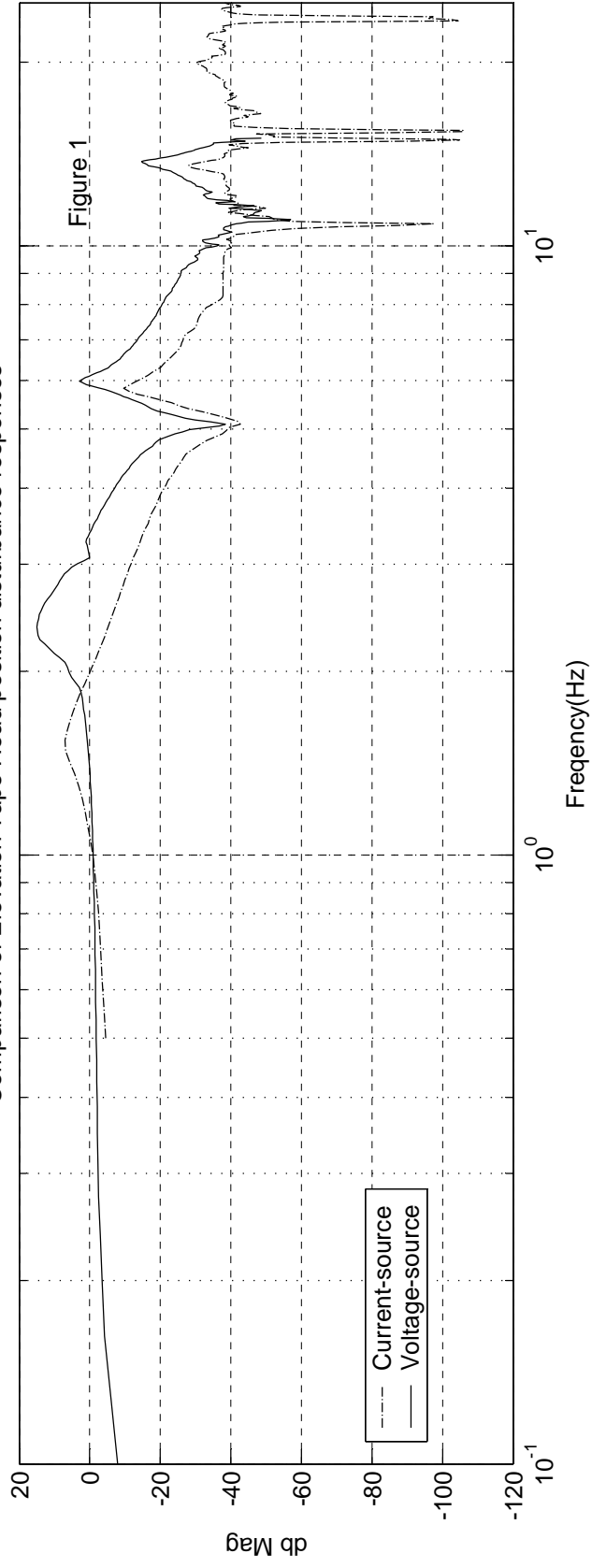
The data in Figure 6 are presented in the same manner as Figure 5, above, for the motor shaft encoder and the azimuth absolute encoder outputs. Again we have good general agreement between the two encoders, but some non-correlated, strong high-frequency energy present.

Conclusion

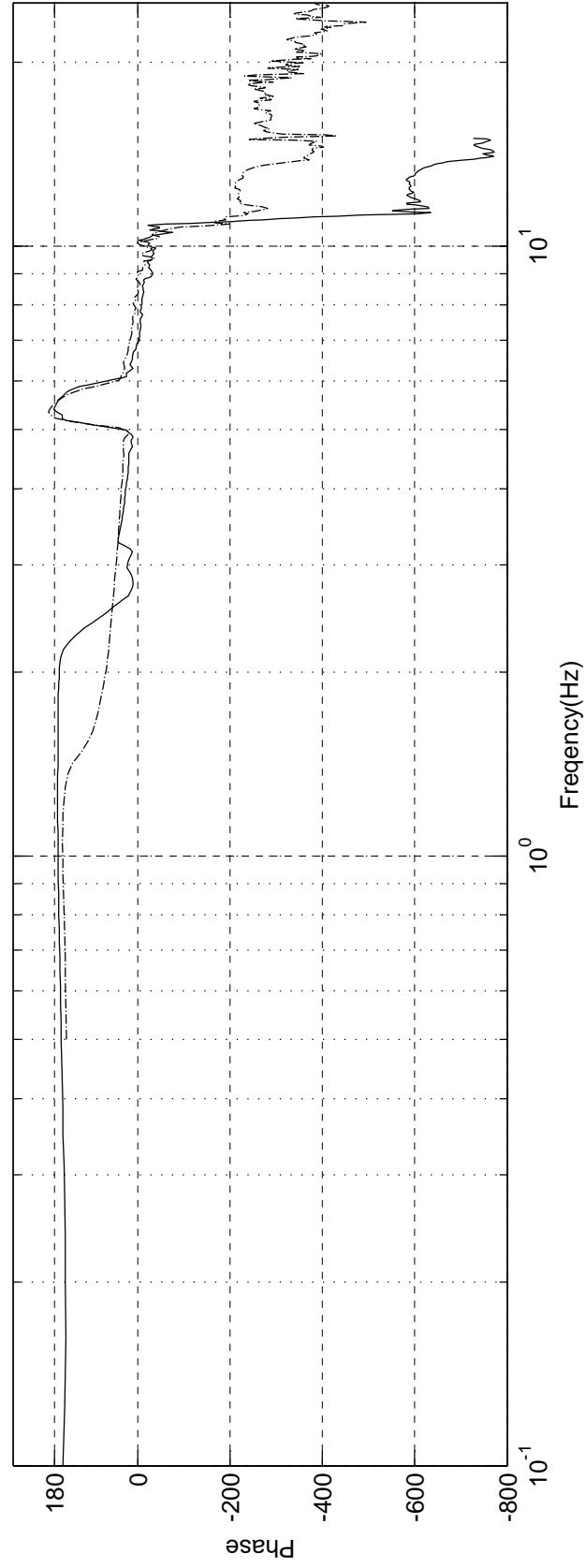
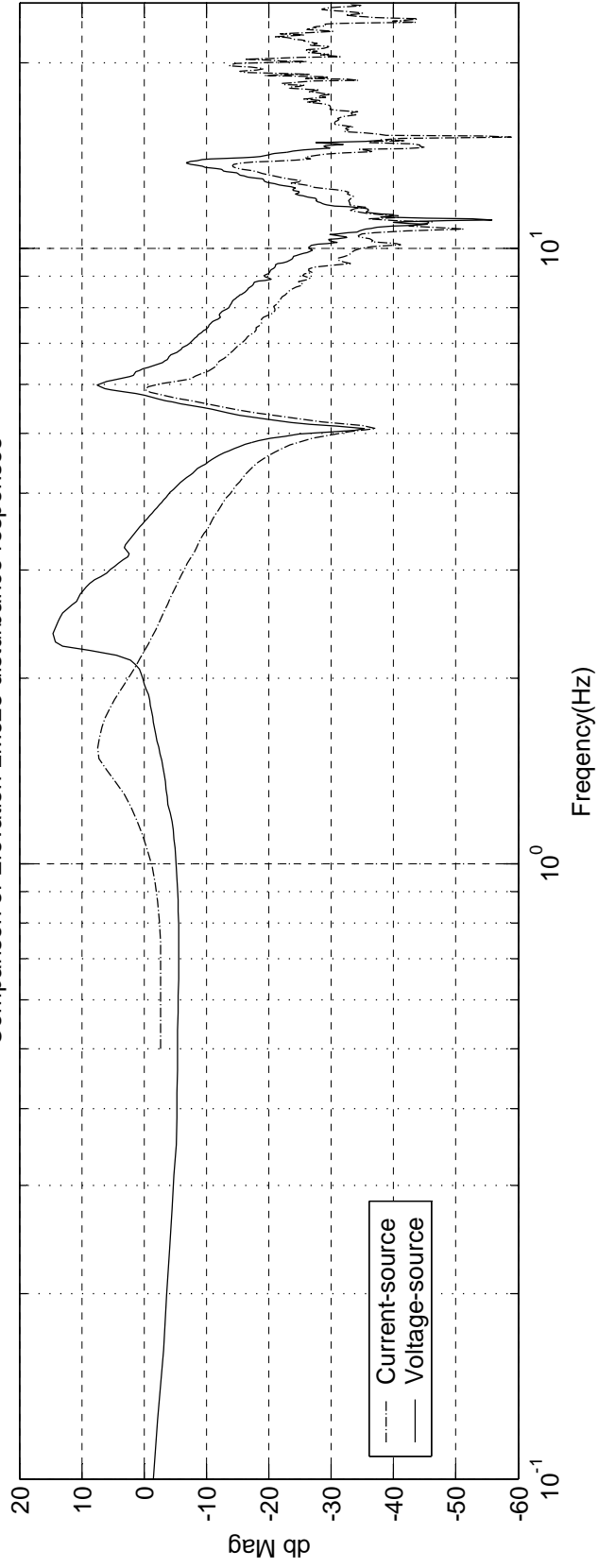
The somewhat odd results of the LM628 transfer function tests dramatically show the reasons for the heretofore poor tracking experienced on the MMT in windy conditions. While no good explanation for the behavior of the velocity loop has yet been found, it has been suggested that the LM628's internal trajectory generator forces the inner loop to try to complete trajectories even when the outer loop is attempting to correct disturbances, resulting in large time delays between the disturbance and amplifier command.

Using the noise response data collected during this testing, it is planned to continue with development of system models of sufficient accuracy for use in evaluating possible replacement control topologies, as well as to attempt to find ways of improving the existing hardware. To this end, a complete motor test stand is being built and the results of a formal identification and design of a new digital controller will be presented in a future report.

Comparison of Elevation Tape Head position disturbance responses



Comparison of Elevation LM628 disturbance responses



Comparison of Azimuth motor position disturbance responses

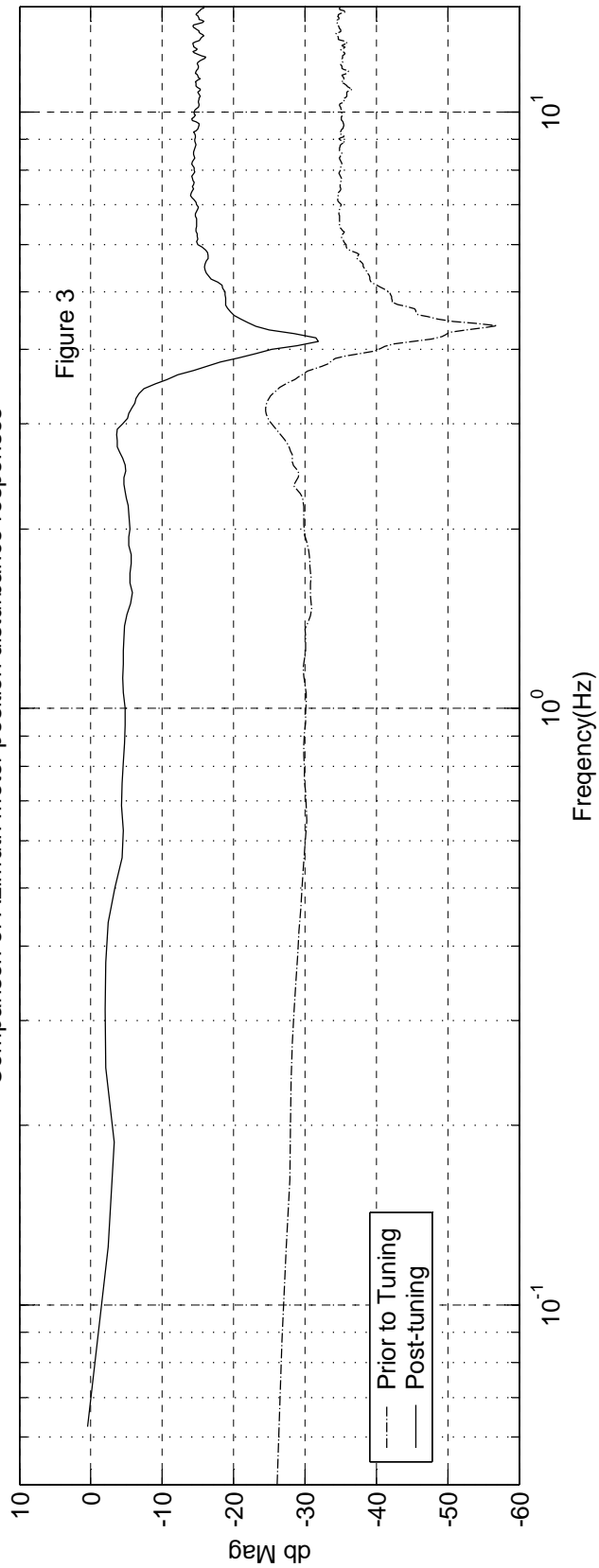
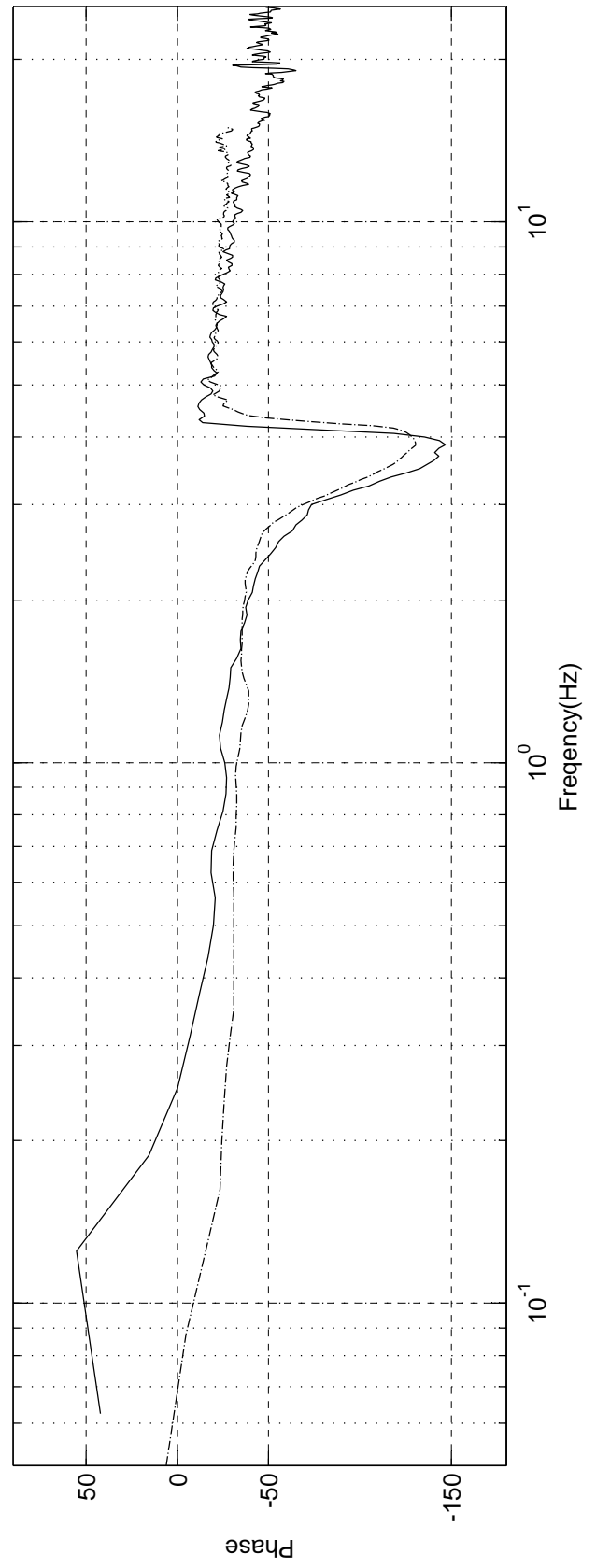


Figure 3



Comparison of Azimuth LM628 position disturbance responses

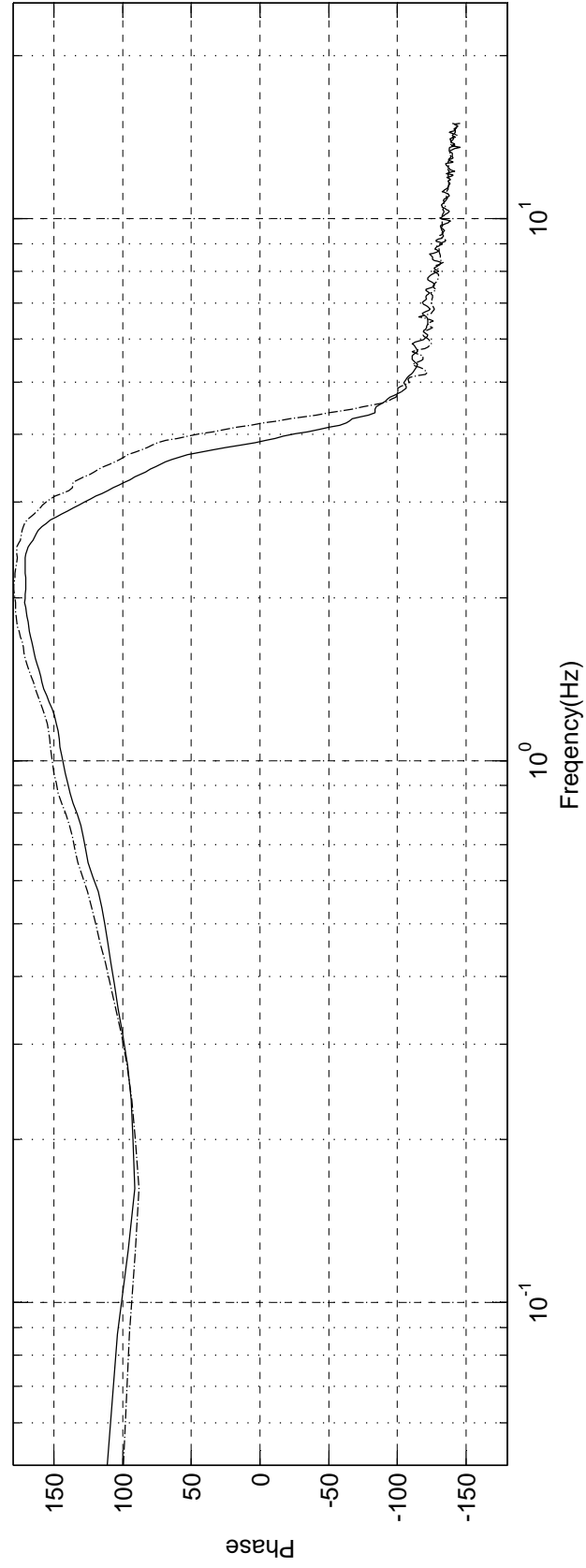
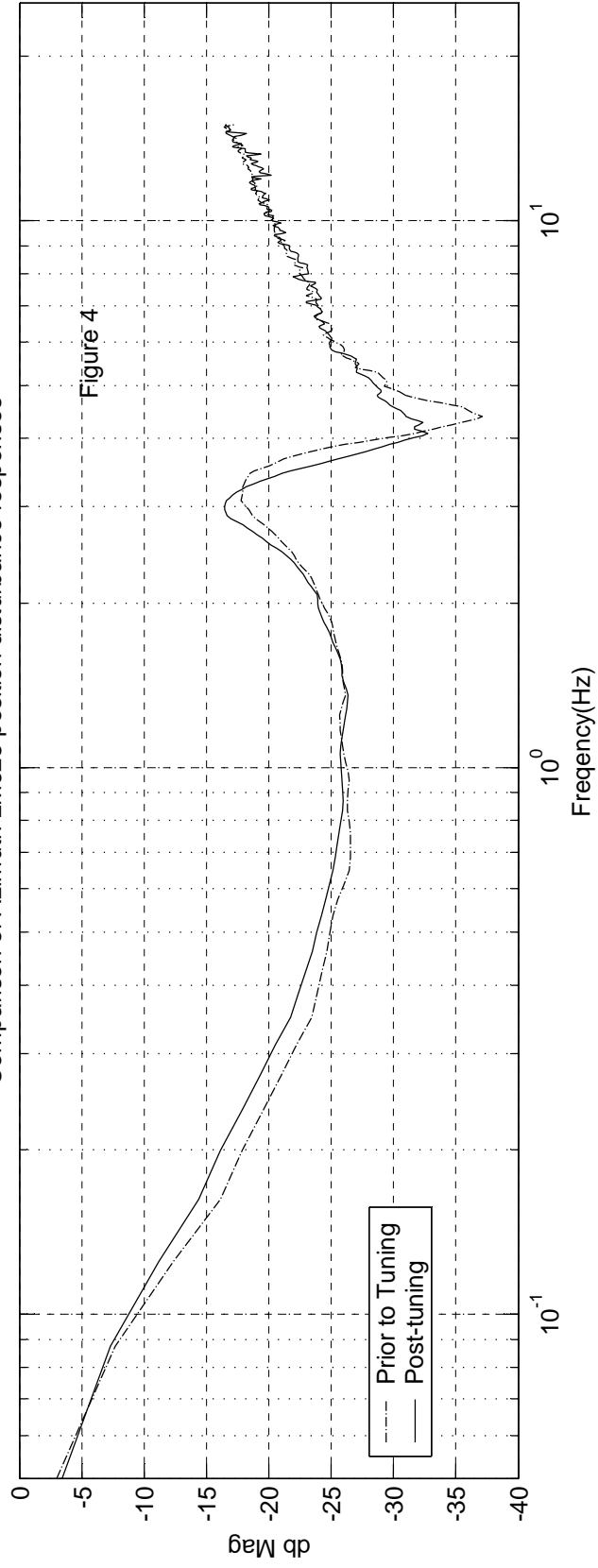


Figure 5 - PSD of Encoder Outputs in 30mph wind

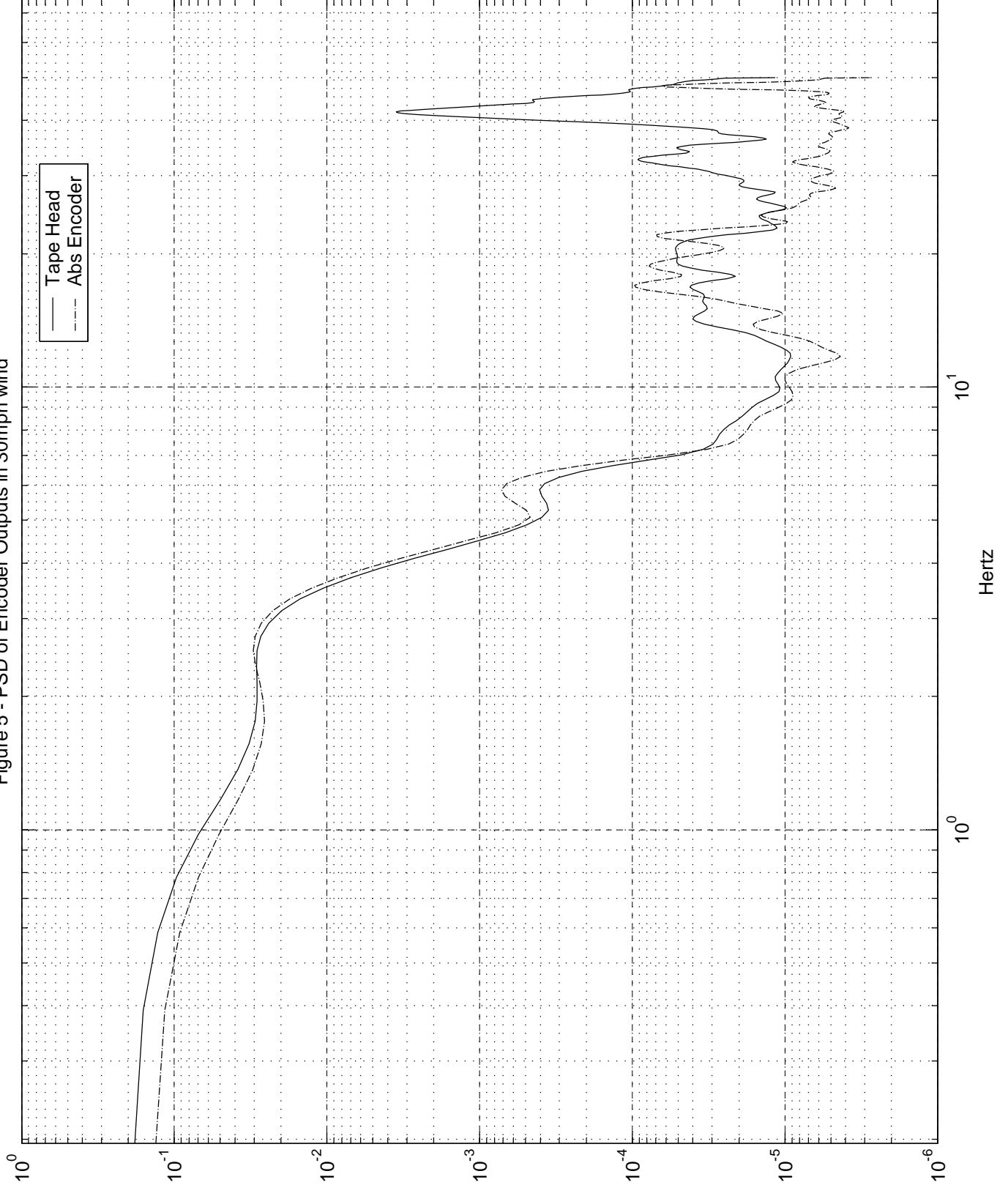


Figure 6 - PSD of Azimuth Encoders in 30mph wind

