2 MICRON CW VIBRATION SENSING LASER RADAR

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ABSTRACT

This paper describes a 2 micron CW laser radar vibration sensor and presents preliminary results from a field trail conducted at Redstone Arsenal during July '98. Data was collected from a variety of targets, at several ranges and varying atmospheric conditions. Also, similar systems with wavelengths at 1.5 and 10.6 microns were operated from the same location and at the same time to allow later determination of the wavelength dependence of signals and interfering effects.

1.0 INTRODUCTION

Coherent laser radar (ladar) has been shown to be a highly sensitive sensor for measuring surface vibrations. For long range vibration measurements, CO2 based lasers operating around 10.6 microns have been used extensively. Advances in solid state laser technology have extended the range of useful wavelengths for laser vibration sensors (LVS) down to 1.5 – 2 microns. With the advent of shorter wavelength solid state laser radar systems, multiple wavelength choices for such sensors have generated questions concerning the optimal laser wavelength for such sensors. An LVS is sensitive to vibration amplitudes that are comparable to the laser wavelength. Therefore, these new shorter wavelength systems are able to measure small vibration induced displacements than their earlier counterparts. While it is generally accepted that shorter wavelength vibration sensing laser radars should be more sensitive to lower amplitude and frequency vibrations, this has not been adequately demonstrated in simultaneous side by side measurements. Shorter wavelengths also can take advantage of increased atmospheric transmission possible by tuning the laser away from water vapor and molecular absorption. While sensitivities may improve at shorter wavelengths, the negative effects of atmospheric turbulence and other phenomenologies increase at these shorter wavelengths. Also, the potential for lower beam divergence at shorter wavelengths has given rise to questions about the effect that the size of the beam on the target could have on the measured vibration spectra. Because most areas of potential targets would not likely move as a solid surface, the effects of target flexing as well as damping would have on the apparent spectrum at different beam widths is also not well known. Because the laser wavelengths are so short compared to conventional radar, features in the surfaces of the target can create effects that cause significant fluctuations in the return signal for only minor changes in the location of the beam on the target. The ability to properly scale laser radar performance specifications and to understand how apparent target vibration signatures may fluctuate during operational scenarios are vital to evaluating the potential utility of such sensors for missions such as target location and non-cooperative identification. This paper will describe a 2-micron LVS transceiver, signal processor and the preliminary results of a field test conducted at Redstone Arsenal in Alabama during July 1998.

2.0 SYSTEM DESCRIPTION

The heart of the LVS is the laser. In this system, a Tm:YALO CW laser operating at 2.02 microns and producing 150 milliwatts provided the laser energy that was used for both the transmitted beam and the reference local oscillator. The output of the laser was fiber coupled to the transmit/receive head, which measured approximately 8" (w) x 12" (l) x 4" (h). In the head, the beam first went through a beam splitter where approximately10% of the beam was split out for the local oscillator and shifted by 27 MHz through an electro-optic modulator. The remainder was expanded and transmitted through the 50 mm transmit telescope. The returning beam backscattered from the target

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was collected in a similar and co-aligned receive telescope. Both the returning beam and the local oscillator beam are combined onto a photo-diode detector. The layout of the transmit/receive head is illustrated in Figure 1.

The technique used to develop the vibration spectra for targets is the spectrogram approach (1). Figure 2 illustrates the spectrogram processor. The returning signal is mixed with the local oscillator and the difference frequency (27 MHz for this system) is then mixed with the IF frequency to generate a low frequency IF (500 kHz). This output is lowpass filtered and then sampled with the 2 MHz digitizer. Samples from the digitizer are then input into a Fast Fourier Transform (FFT). Centroiding then determines a frequency estimate for that sample. This correlates to a velocity and a time history of such velocities is built up to input into a second FFT. The output of this second FFT processor is the vibrational frequency spectrum. This system develops velocity estimates at a 2 kHz rate yielding a Nyquist frequency capability of up to 1 kHz.

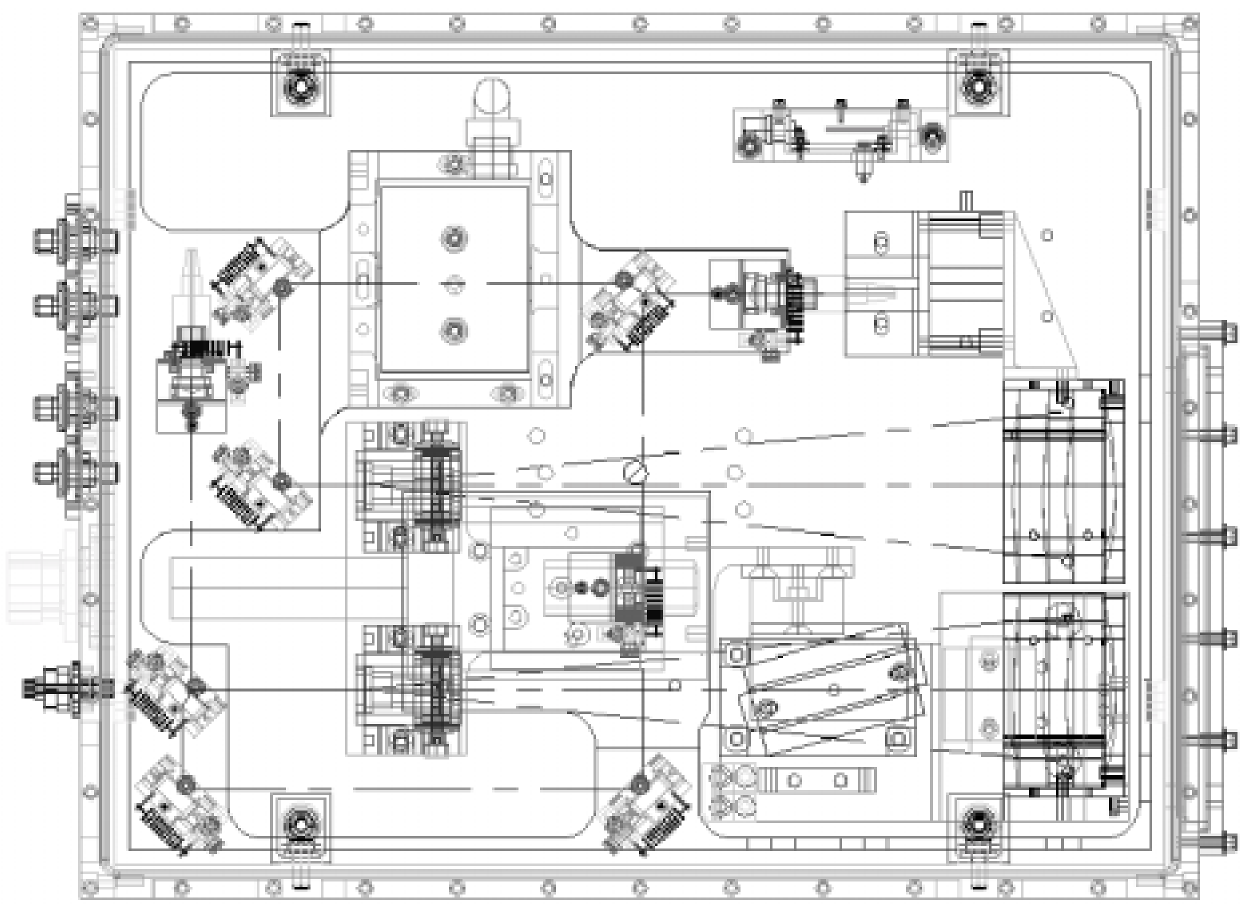

FIGURE 1: Schematic of laser vibrometer transmit/receive head

1. Kachelmyer, A.L., Shultz, K.I., “Laser Vibration Sensing”, *The Lincoln Laboratory Journal*, Vol 8, Number 1, 1995

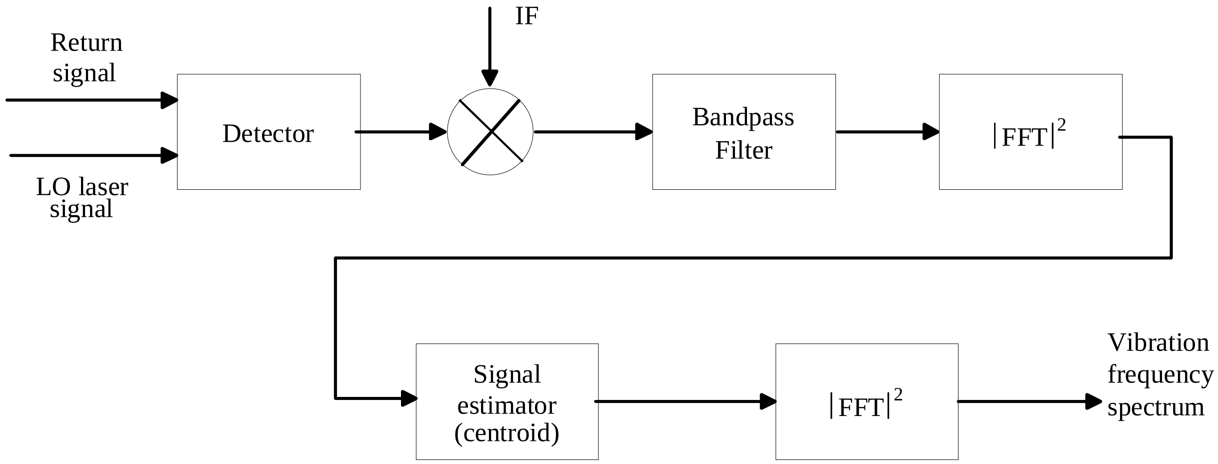

FIGURE 2: Block diagram of CW spectrogram processor.

Figure 3 further illustrate the processing used in this system. The solid line represents the variations in the Doppler shifted signal out of the second IF amplifier. That is a 500 kHz signal with vibration induced fluctuations imposed on it. The points marked with small squares are the actual points sampled by the digitizer. It is the spacing between these points that determine the upper Nyquist limit to the spectrum that can be derived from this signal. When a sufficient number of these points have been read into the DSP, the second FFT yields the spectrum illustrated in Figure 4.

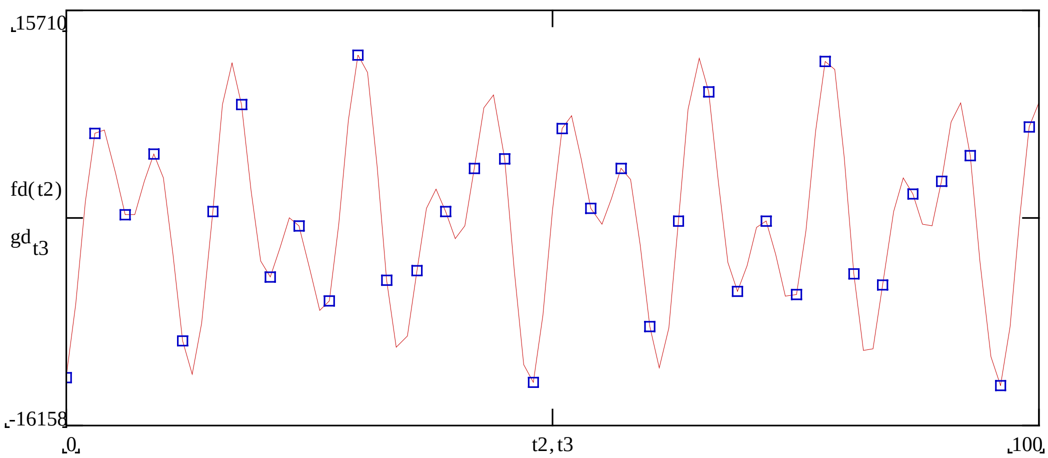

Figure 3. Representation of discrete return signal sampling. Spatial and velocity fluctuations due to 50 and 87 Hz vibrations.

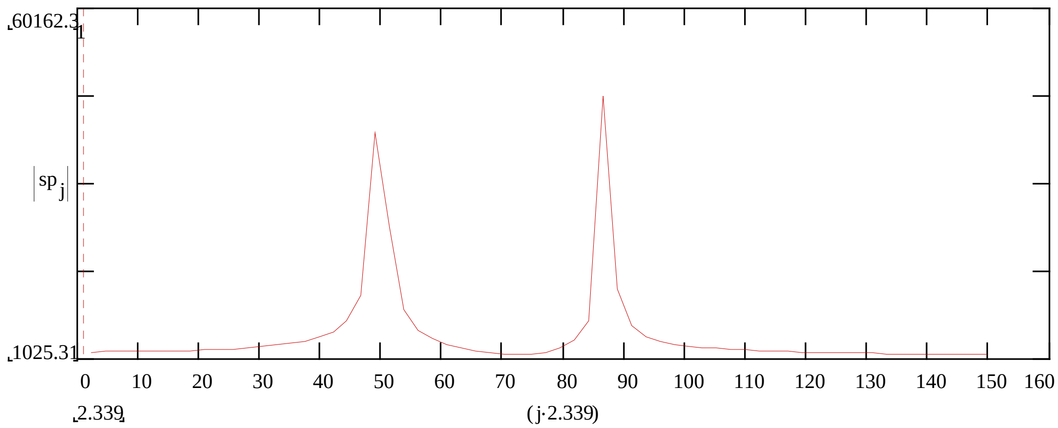

Figure 4. Spectrum derived from FFT of samples in Figure 3.

3.0 TESTING

3.1 Performance Predictions

The system, target and atmospheric parameters shown in Table 1 were used to predict the range performance of this system. Using the standard laser radar equation, CNR curves were generated for the 2 atmospheric conditions in the table. These results are shown in Figure 3. Velocity, and ultimately frequency, accuracy is affected by the CNR. Earlier experiments have shown excellent accuracies with CNR's of 10 dB or more. Looking at Figure 1, the useable range for the system could be in excess of 2.5 km even for relatively poor atmospheric conditions.

Table 1 - Values used for performance predictions

Parameter	Value
η - heterodyne efficiency	0.25
P - transmitted power	150 mw
$h\upsilon$ - photon energy	10^{-19} J (λ= 2 μm)
B (1/T) - bandwidth	10 kHz (T=100 μs measurement)
D - receiver aperture	4 cm (1/e^2 Gaussian diameter)
ρ - target reflectivity	0.05 sr^{-1}
K^2, C_n^2 - atmospheric attenuation and turbulence	-0.7 dB/km and 2x10^{-14} $m^{-2/3}$ for 2065.48 nm propagation along a horizontal path in a clear, weakly turbulent mid-latitude summer atmosphere
K^2, C_n^2	-2.4 dB/km and 2x10^{-13} $m^{-2/3}$ for a hazy, moderately turbulent atmosphere

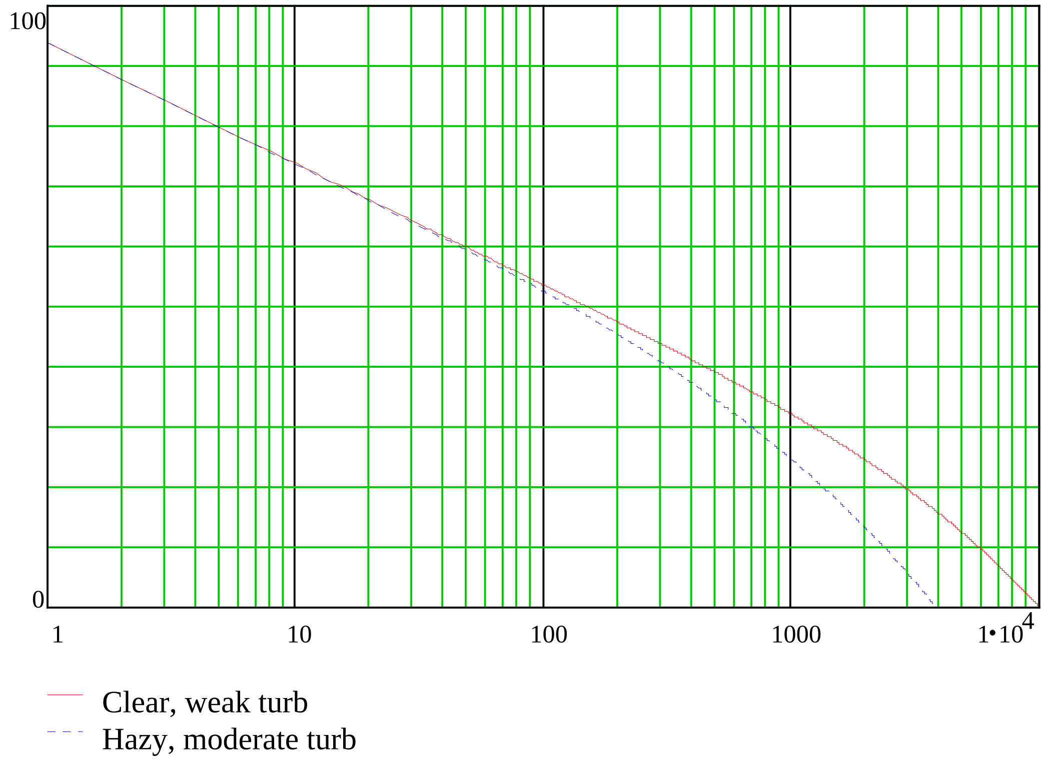

Figure 5. CNR (dB) vs. Range (m) for different atmospheric conditions

3.2 Huntsville Field Trials

In order to address some of the questions concerning wavelength dependence on LVS performance, this 2-micron system was one of the LVS systems operated during a NATO sponsored field trial hosted by the US Army at Redstone Arsenal in Huntsville Alabama. The tests took place during July 1998 when normal levels of heat, humidity and solar heating induced refractive turbulence are high. The objective of this effort was to improve our understanding of how phenomenologies such as atmospheric turbulence and attenuation affect the performance of laser radar vibration sensors. Scaling these effects with laser wavelength was also an important part of the purpose of this effort.

3.2.1 Site Description: At the test range, the LVS systems were housed in shelters located on top of a mound at the southern end of the range. The mound was approximately 5 meters high an offered an unobstructed view of the range. The terrain of the range was slightly rolling and grass covered. Targets could be placed within the range at distances of up to 5 km. Sensors for measuring visibility and turbulence were also operating during the tests. Typical battlefield obscurants such as white phosphorus (WP) and fog-oil could also be generated during the tests.

3.2.2 Test Targets: Targets available during these tests included: a M2 Bradley, M60 Tank, T-72 soviet tank, and US and soviet armored personnel carriers. A partial listing of the targets, ranges and measuring points is given in Table 2.

Target	Range (m)	Position	Sample Point	Obscurants
Bradley	500	Side view	centered	
BMP	530	Side view	centered	
T-72	1035	Side view	centered	
BMP	1030	Side view	centered	
BMP	“	“	rear	
BMP	“	“	front	
BMP	1020	Side view	front	WP
BMP	560	Side view	rear	Fog-oil
M-80	1000	Side view	turret	
M-60	980	Side view	turret	
M-80	1000	Side view	centered	
T-72	1035	Facing sensor	centered	

Table 2: Redstone test data sets

3.2.3 Test Results: Figure 6 is a 55-second time history of the spectrum obtained from a tank located at 1000 meters. The tank was viewed from the side and the measurement point was at the front end of the tank body. As can be seen from this figure, there is a strong line in the spectrum around 59 Hz. There was an obvious concern that this line was actually a noise signal from the 60 Hz power. In order to test this, the aim point of the LVS was moved from the tank to the ground nearby. At that point, the signal went away, confirming that the signal was actually coming from the tank. The next figure (Figure 7) shows the spectrum obtained over 47 seconds from an aim point located near the center of the target body. Here again, the 59 Hz signal is apparent, although the magnitude is lower and much more noise is visible in the spectrum.

The next set of spectra (Figures 8 & 9) are from an armored personnel carrier (APC) viewed from the side. In Figure 8, the target is at 1000 meters and viewed through clear air. Total time is approximately 70 seconds. In Figure 9, the target is at 560 meters and the total time is similar to the previous figure. At the beginning of this data collection, a fog oil smoke generator located upwind from the target by about 50 meters was started. Approximately half way through the measurement, the fog completely obscured the target. Although the smoke was totally opaque in the visible, there was no discernable change in the return signal carrier-to-noise or in the spectrum magnitudes. Preliminary measurements of the fog particulate indicated that the mean particle size was around 3 microns.

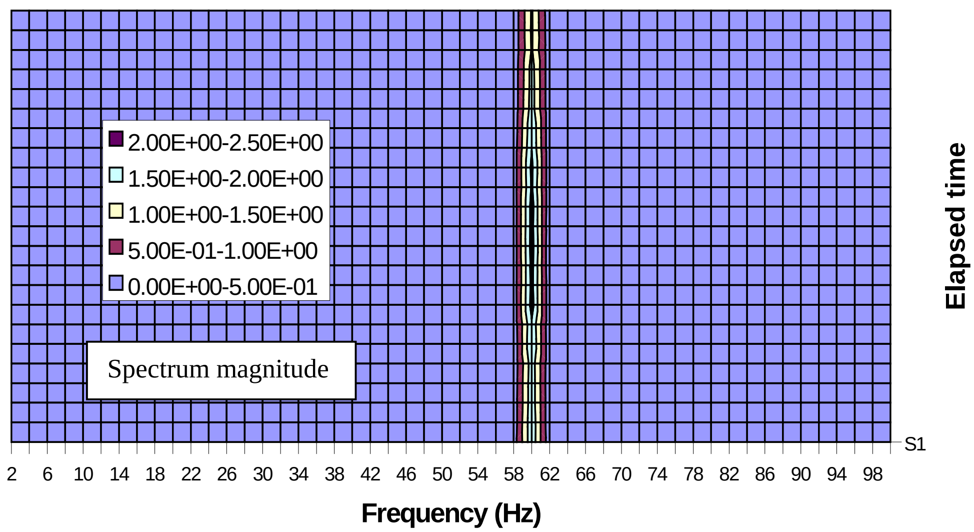

Figure 6. Spectrum from tank at 1000 meters. Sampled near front of body.

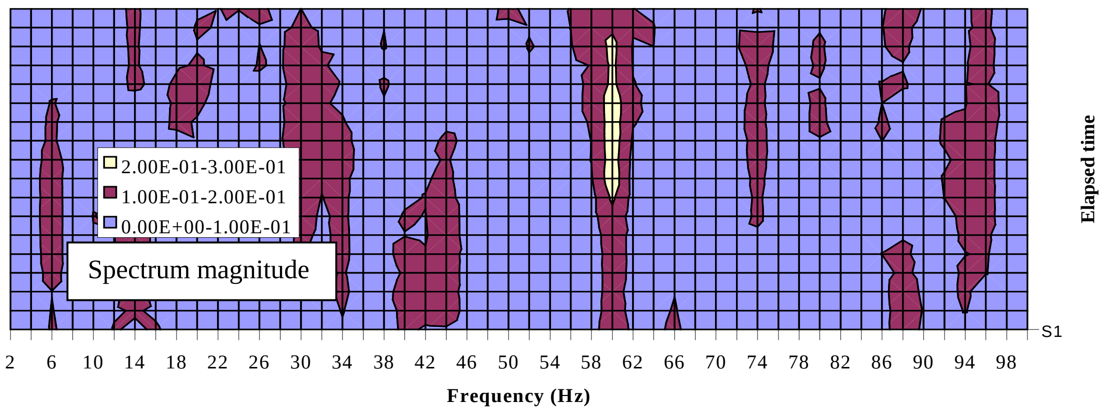

Figure 7. Spectrum from tank at 1000 meters. Sampled at center of body.

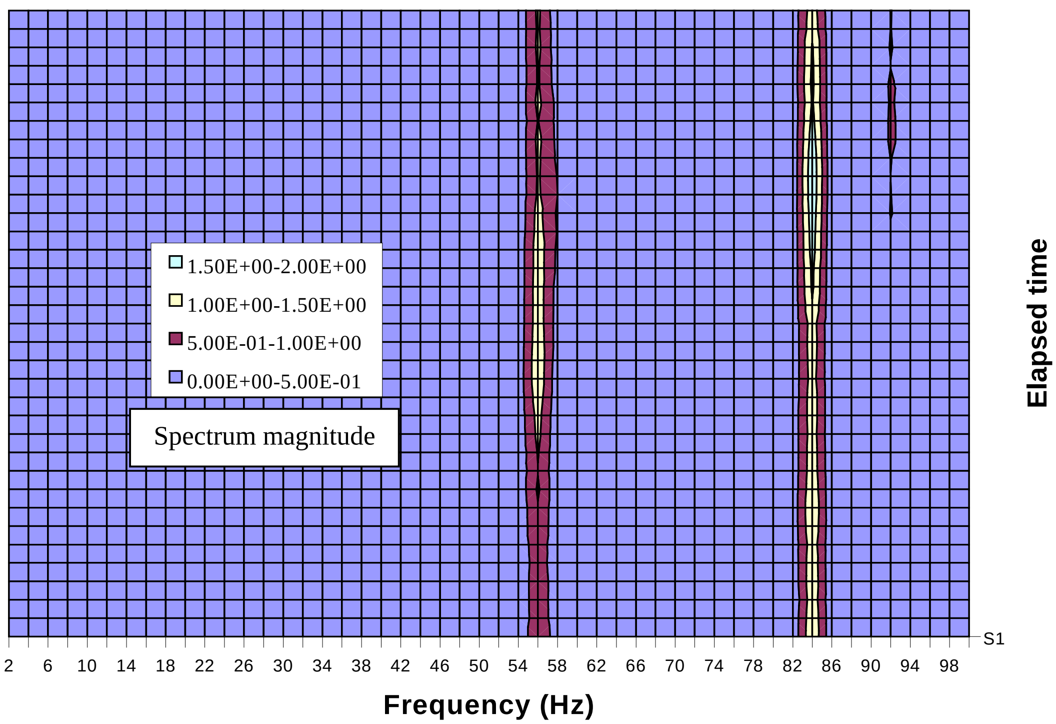

Figure 8. Spectrum from APC at 1000 meters with no obscurants

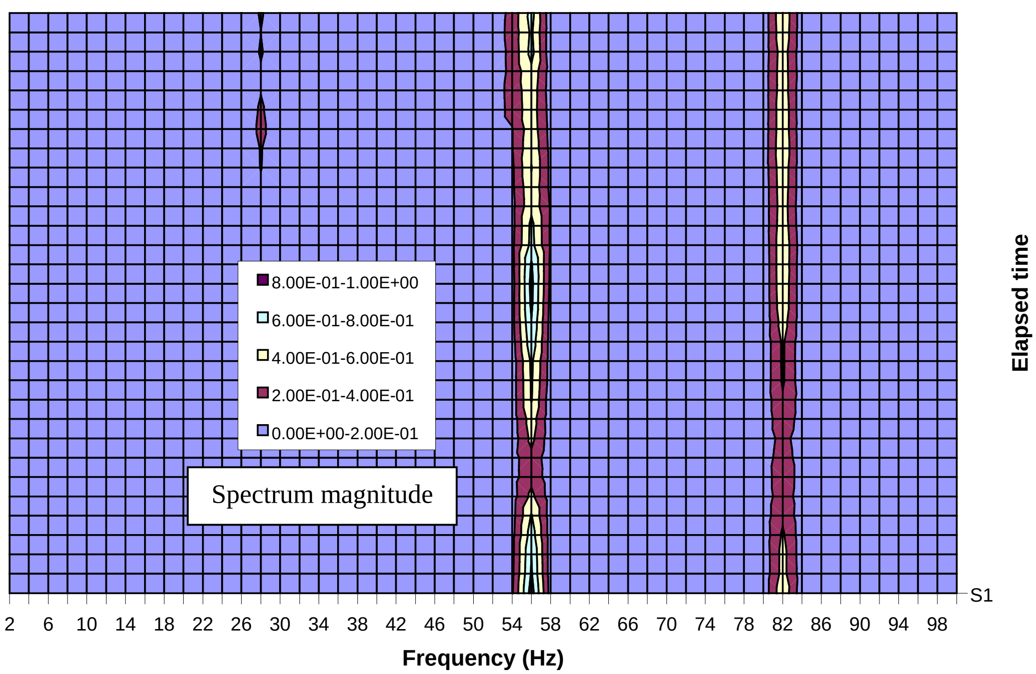

Figure 9. Spectrum from APC at 560 meters during fog-oil release

3.2.4 Atmospheric Effects: At the shorter wavelength used by this system (compared to the CO_2 laser based systems used previously), atmospheric turbulence (Cn^2) could have a significant impact on the range capability of the ladar. Figure 10 illustrates the predicted effect of turbulence on this sensor. The range is set at 560 meters and the other system parameters are the same as in Table 1. The solid line graphs the chance in CNR(dB) with changes in Cn^2 over the normal range of expected values. The time and location of the tests (July in Huntsville) were chosen because normal summer heat and humidity levels could be expected to produce large values and changes in Cn^2. Unfortunately, the weather during the tests was unusually mild and stable with very low levels of turbulence even near the ground and along the sight path of the laser sensor. Figure 11 displays the measured Cn^2 on the day that the highest level was recorded. Even though the spike ($8.9x10^{-14}$) in the curve is a couple of orders of magnitude higher than the lows, that level has only a minimal effect on SNR. The boxed point in Figure 9 points to the drop in SNR for that level of turbulence. The reduction is less that 3 dB. The other problem with trying to correlate turbulence measurements with the ladar signal is the long interval between turbulence measurements. These measurements were recorded at 1 minute intervals and represent an average during the period. The ladar was making measurements at kHz rates and generating spectral estimates every second. Each measurement could be taken through a significantly different turbulence level never seen on the longer scale.

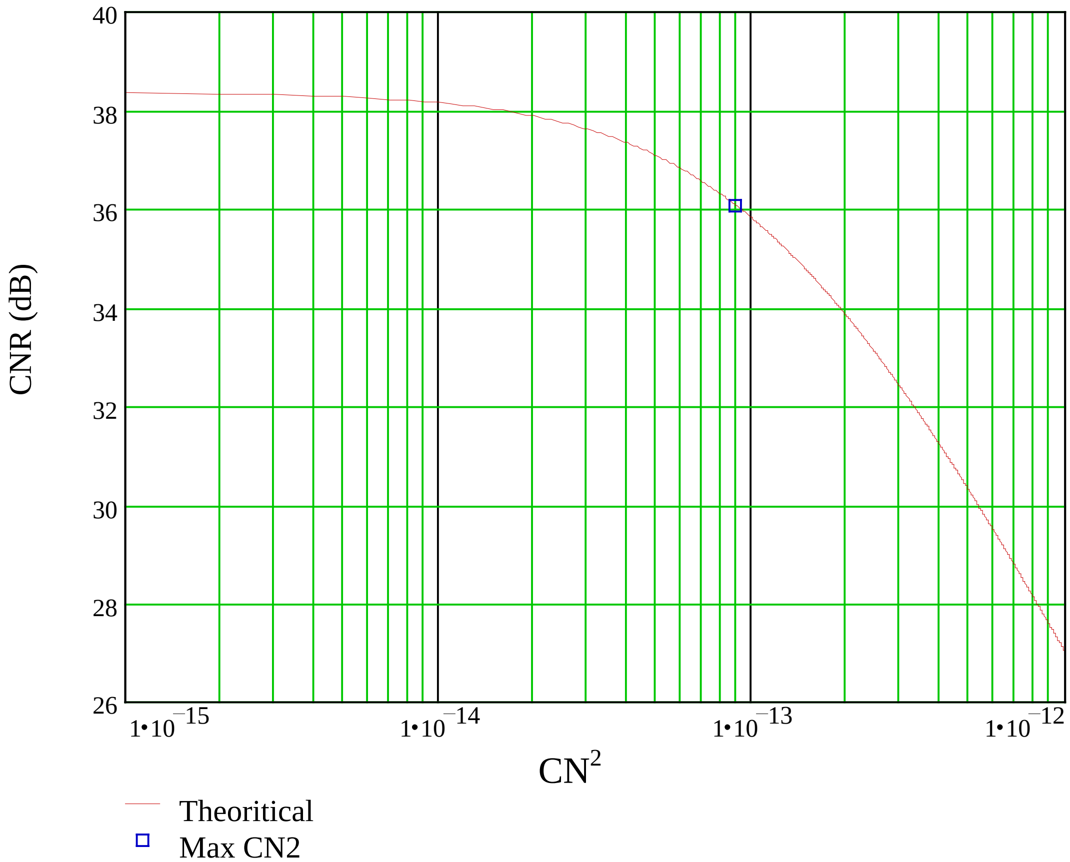

Figure 10. CNR (dB) vs. Cn^2 with target at 560 meters

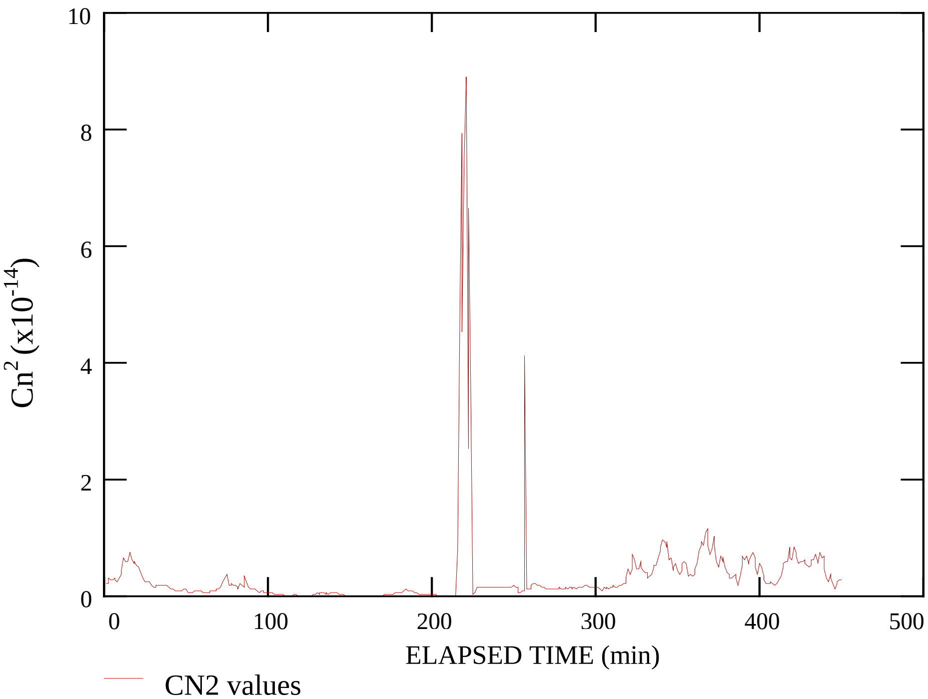

Figure 11. Measured CN^2 values

4.0 CONCLUSIONS

A significant amount of data has been collected under a variety of atmospheric and seeing conditions. The data presented here have illustrated the viability and robustness of shorter wavelength laser vibrometry systems. Of particular interest was the result from the fog-oil tests. There would have been little or no absorption of the signal by the fog-oil, but the particle sizes should result in relatively large scattering of the laser energy. The results would be a rather large effective attenuation (sum of but the absorption and backscatter). Although the sample set is too small to draw any firm conclusions, the fact that no apparent increased attenuation was observed could significantly impact perceptions about laser based sensor performance in the presence of battlefield obscurants. Only a small sample of the data collected during this trial has been processed and analyzed. Much work remains to be done on correlating measured signal strengths and atmospheric conditions and the effect of these phenomena on the ability of the sensor to monitor spectra. Also, in the coming months the various researchers involved in this test will be comparing results in an attempt to quantify wavelength dependencies. However, we are pleased with the results obtained so far and consider the test to be a real success.