Measuring and describing seismometer noise (for dummies)

There have been many papers written about measuring seismometer instrument and site noise. However, these usually started with some assumptions about what I already knew, which was, in fact, practically nothing. This is intended to start from pretty much where I started and arrive at the point where the reader can begin to understand noise plots and technical documents written about seismometer noise.

Describing the internal noise of an instrument or the background noise at a site is important, as it defines the effective sensitivity of the seismic measurements which can be made there. It is easy to increase your display sensitivity to the point that the instrument and background site noise will obscure any ground motion from weak earthquakes. Simply put, the lower your noise, the weaker the quakes you can see.

Noise is usually described in the form of a frequency spectrum, very much like you might obtain in WinQuake when using its FFT function on a time segment of recorded data. The spectrum is almost always plotted on logarithmic axes where the distance along a scale represents a ratio of the variable being plotted. On the vertical axis this is sometimes done by plotting in units of dB, which are computed from the logarithm of the ratio of the plotted value to a stated reference value.

If you aren't already familiar with WinQuake's Fast Fourier Transform, FFT, capability, I would recommend your learning to use it, as it is quite similar to the process used when making noise plots. With it, you start from a time-series of numbers, such as the digitizer count values describing instantaneous ground velocities, which were sampled at a known rate for a particular time period. From them you create a signal spectrum, plotted as a function of frequency. The frequency range of the spectrum, at the low end, will depend on how long a time period is contained in your data while the high end will depend on your data sample rate.

The most common way of plotting noise is by some form of Spectral Density or Power Spectral Density, PSD, and here we will examine how to interpret such a plot.

When looking at a chart describing noise, you should first look at the axis labels and their units in order to understand what you are seeing.

Horizontal, frequency axis:
Normally noise is plotted as a logarithmic function of frequency, similar to the WinQuake FFT plots. In such a plot each unit of distance represents the same ratio of frequency, usually apparent as 10:1 decades. However, you will often see noise plotted in terms of period, the reciprocal of frequency, which puts high frequencies to the left and low frequencies to the right. Or I have seen one plot provided by Nanometrics, in which the x axis values were labeled as Period, but plotted from right to left so that the high-frequency end of the spectrum plot remained on the right.

Vertical, axis:
First look at the units. There are multiple ways of plotting signal spectra, and the units on the axis will tell the story as to what the data represent.

Like the recorded time-sampled data themselves, seismic spectra can be plotted in terms of displacement, velocity or acceleration. Or by squaring those data values, they can be converted to spectral "power". When describing noise, power is the parameter most often used, as noise powers from various sources may be directly added to arrive at total noise.

In order to have physical meaning, a signal spectrum must always be described in terms of spectral density. In terms of power, at a particular frequency, that would be defined as the total signal power contained in a specified narrow band, centered on that frequency and normalized to a bandwidth of 1Hz by multiplying each value by 1Hz/width of the chosen measurement band. Or it can be plotted as the square root of that value. In fact, the FFT spectrum plots generated in WinQuake are actually spectral densities, though WinQuake throws away any reference to units, and instead uses undefined ones of its own, which it chooses simply to fit the range of data values to the screen.

Units:

Power spectral density of acceleration
m^2/sec^4 per Hz or sometimes m^2/sec^3 since Hz = sec^{-1}
These are computed by squaring the m/sec^2 acceleration sample values and normalizing to 1Hz bandwidth.
These are by far the most commonly used PSD units and are the units used in the various earth noise models, except that they were initially defined and plotted vs time *period* rather than frequency. These would usually be plotted as dB vs 1 m^2/sec^4 per Hz or equivalently, vs 1 m^2/sec^3, where dB = 10 $\log_{10}$ of the ratio of the plotted power density value to a reference power density, usually $1m^2/sec^4$ per Hz.

Acceleration spectrum or spectral density
m/sec^2 per $\sqrt{Hz}$
computed directly from the values of the acceleration samples without squaring.

From a data series described by velocity, such as we normally get from WinSDR, the acceleration spectral density may be obtained by computing the velocity spectrum, then multiplying each data point by 2π f, where f is the frequency for that point.

Velocity spectrum or velocity spectral density
m/sec per $\sqrt{Hz}$ or m $sec^{1/2}$
This is what is plotted by WinQuake FFT's, assuming that your .psn event time-series data represents ground velocity, i.e m/sec. or cm/sec.