Troubleshooting Low Noise Systems

INTRODUCTION

The exceedingly low level of electronic noise produced by the QCL family of drivers makes narrower linewidths and stable center wavelengths possible. To take advantage of the lower noise, different troubleshooting methods are required. The QCL driver noise level is low enough that formerly masked systemic electronic noise becomes a dominant contributor. Externally coupled noise sources from both conductors and electromagnetic radiation become increasingly noticeable factors in controlling laser linewidth or center wavelength stability.

Low noise design and measurement techniques require patience and persistence. We recommend a reductionist approach to all aspects of low noise measurement and troubleshooting. Begin by reducing the system to individual components. Verify the performance of each component individually. Add components back to the system one at a time and check the combined noise at each step. Assume the connectors and cables are possible noise sources as well. Using this method, excess noise contribution becomes easier to identify in both the signal path and measurement systems. An excellent resource is *Noise Reduction Techniques in Electronic Systems*, 2nd Edition (Wiley, New York, 1988), Henry W Ott.

With this Application Note, we establish baseline noise levels to expect as each element is added to the measurement system, discuss common noise sources, and present possible ways to eliminate them.

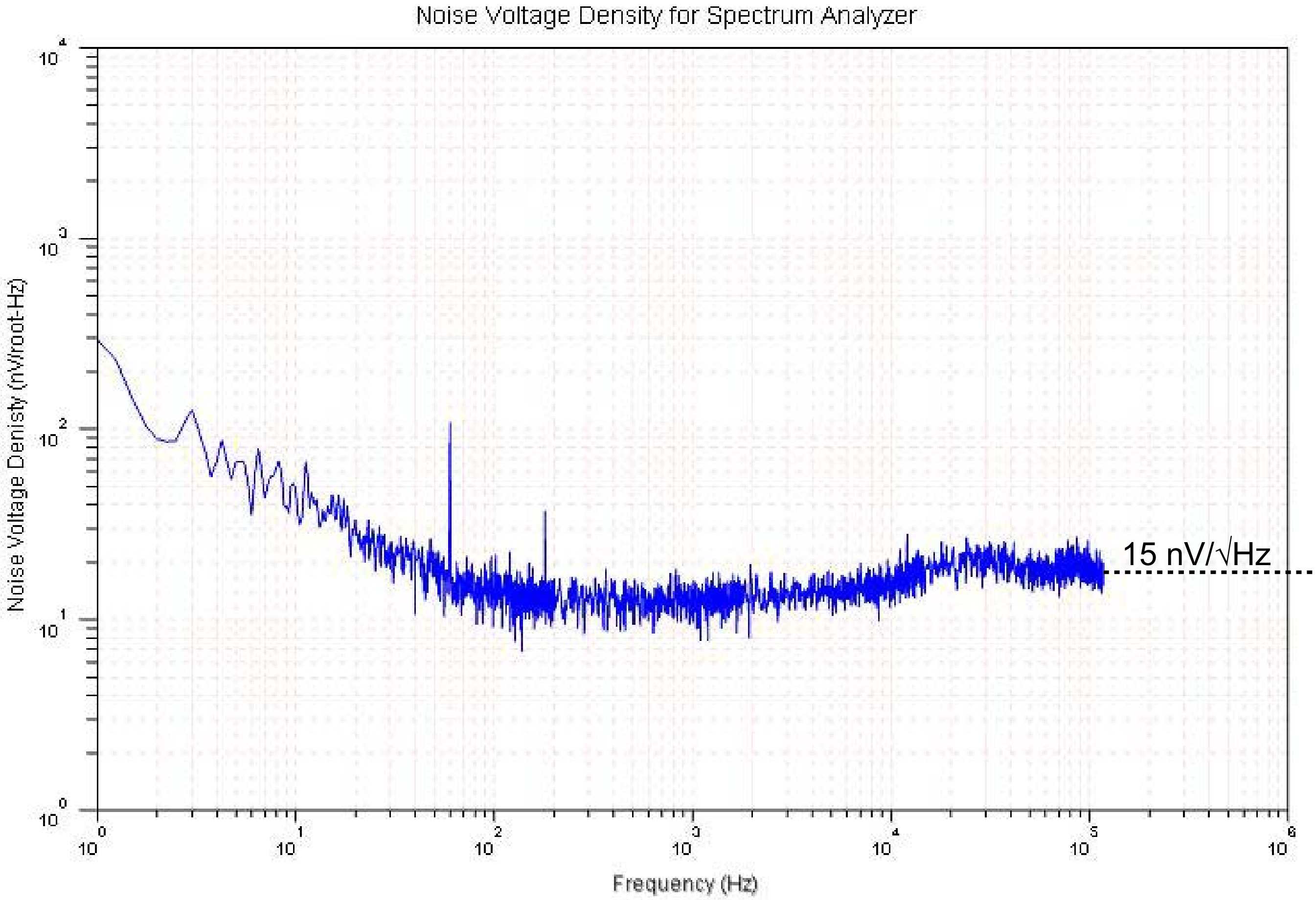
NOISE MEASUREMENT SYSTEM BASELINES

System noise analysis most often requires frequency domain measurement. A high quality spectrum analyzer is the core of the measurement system. To establish its noise floor, connect the input to ground and look at the resulting spectrum. To be effective at the levels of the QCL drivers, its noise floor needs to be less than 50 nV/√Hz across frequencies. In the Wavelength Electronics measurement system, the spectrum analyzer noise floor is at 15 nV/√Hz at 1 kHz. Figure 1 shows our noise floor.

The Wavelength Electronics test system includes an external pre-amplifier to bring the Device Under Test (DUT) noise characteristics to an amplitude well above the noise floor of the spectrum analyzer to effectively lower the system noise floor. This pre-amplifier is not required for spectrum analyzers with internal pre-amplification.

Battery powered pre-amplifiers offer the lowest noise performance. An AC coupling filter at the pre-amplifer input protects the downstream system from inadvertent DC overload. To establish the noise floor of the pre-amplifier and spectrum analyzer combined, ground the pre-amp input, and connect the pre-amplifier output to the spectrum analyzer. Note that the cable in our system is six-foot RG-58 coaxial cable with a 50 Ω matched termination.

Figure 1: Spectrum Analyzer Noise Floor

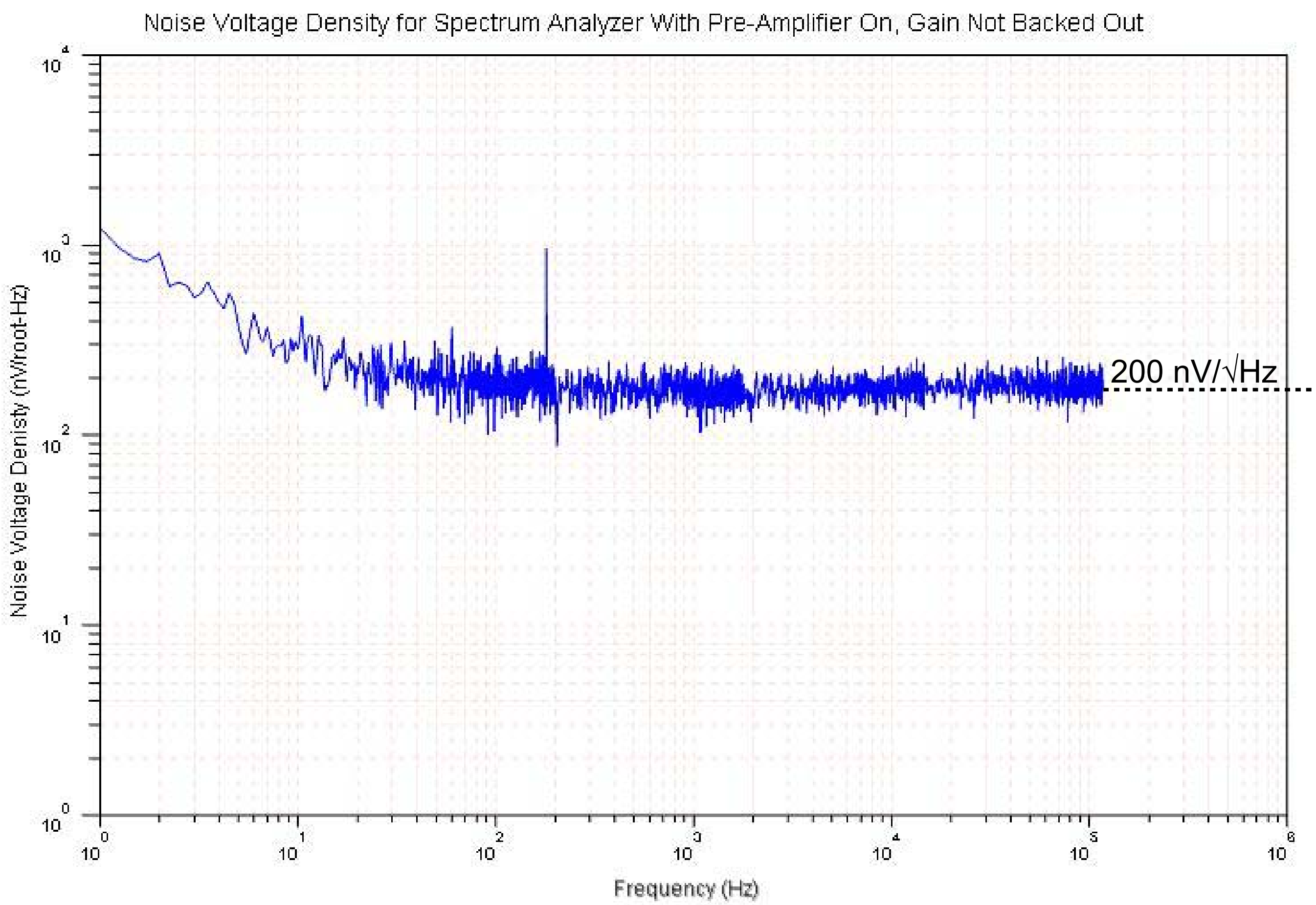


Measure the noise floor with the pre-amplifier powered off, then again when power is applied. The noise floor with the pre-amplifier off should be at or very near the noise floor of the spectrum analyzer alone. Expect this connection to increase power line (50/60 Hz) related noise. Significant broadband noise additions point toward a problem with the cabling. Inspect connectors and shielding, if necessary. With the pre-amplifier powered up and set to a gain of 100, the combined noise floor needs to be less than 500 nV/√Hz across the majority of the spectrum. 1/f noise may increase moderately at frequencies below 10 Hz.

Figure 2: Test Set-up

Figure 3 below is a snapshot of our measurement baseline. The first graph in this sequence shows the pre-amplifier output with no adjustment made for internal gains. The noise floor is well above that of the spectrum analyzer and maintains a flat profile between 100 Hz and 100 kHz.

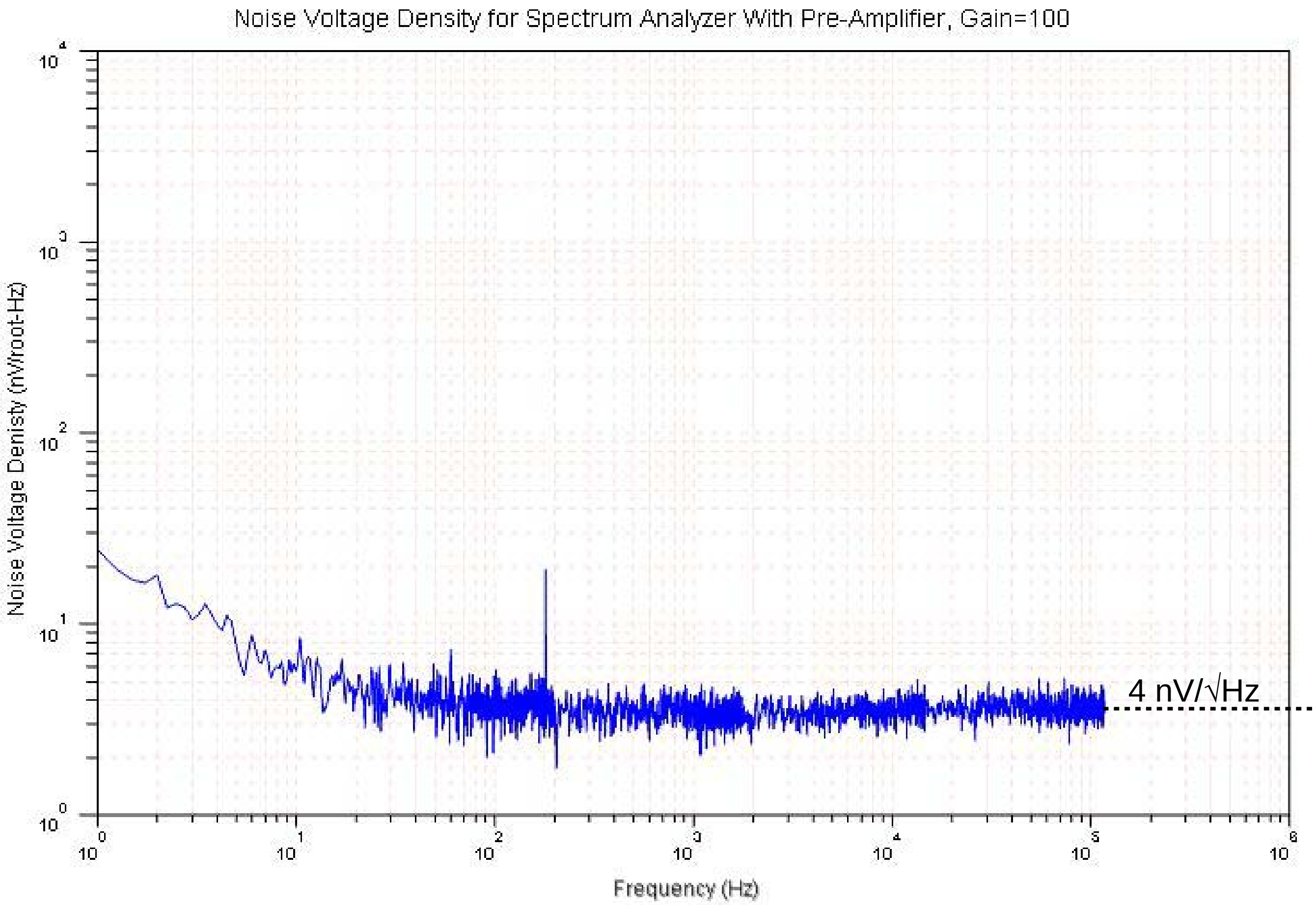
Figure 3: Pre-Amp OFF (Gain Not Divided Out)



The graph in Figure 4 backs out the pre-amplifier gain and the 50 Ω matched termination. The signal into the pre-amp is 100x lower and halved by the 50 Ω termination. So the average 200 nV/√Hz signal starts as (200 nV / 100) * 2 = 4 nV/√Hz.

The pre-amplifier advertised input noise density is 4 nV/√Hz, so our measured results match expectations. The system noise floor is now 4 nV/√Hz.

Figure 4: Pre-Amp ON (Gain Divided Out)



A good reference at this point is to measure the Johnson voltage noise density of a resistor. Connect a 10 kΩ resistor to the input of the pre-amplifier and verify that the reading on the analyzer corresponds to the expected Johnson noise, added in quadrature to the pre-amplifier input noise.

Johnson Voltage Noise Density:

$$\sqrt{4k_B\, T\, R}$$

where
k_B = 1.38 x 10^{-23} [Boltzmann's constant]
T = 300 K, and
R is in Ω

10 kΩ Resistor noise (at 300K) =

$$\sqrt{4*(1.38)^{-23}*300*10^{4}}$$

= 12.9 nV/√Hz

Add noise in quadrature.
Total Noise =

$$\sqrt{\left(Noise_1\right)^2 + \left(Noise_2\right)^2}$$

Pre-amplifier noise = 4 nV/√Hz

Combined noise =

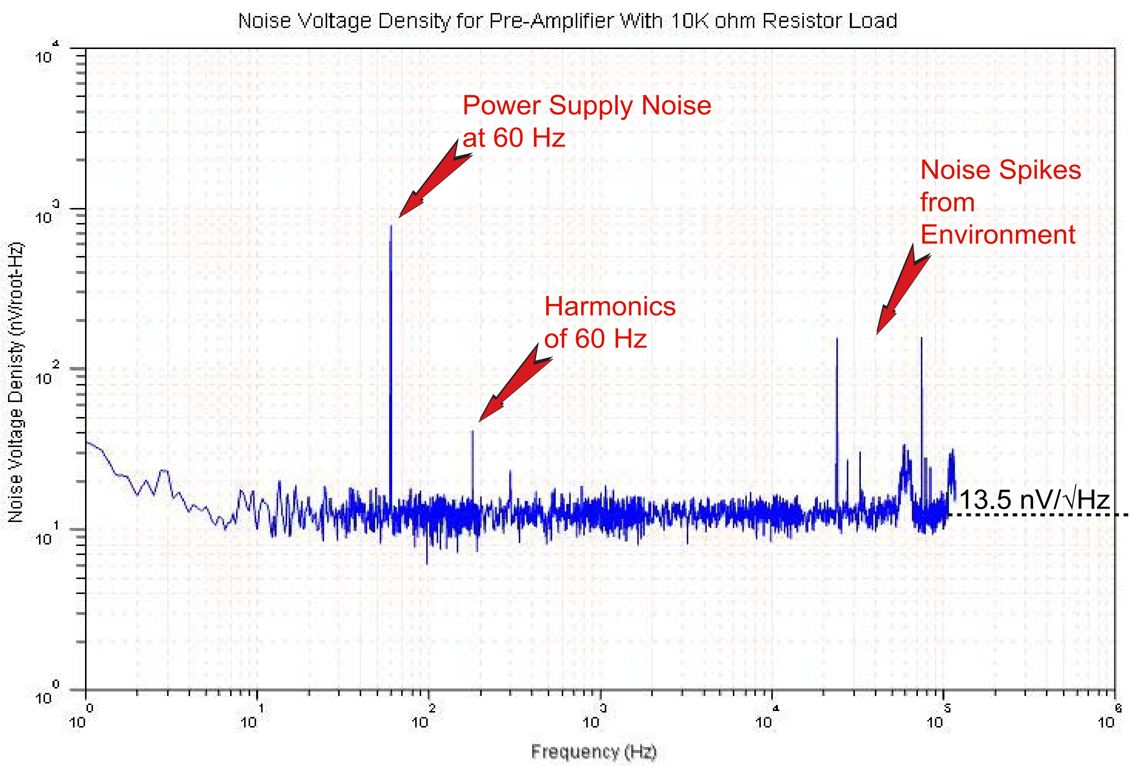
$$\sqrt{\left((12.9)^{-9}\right)^2 + \left(4^{-9}\right)^2}$$

= **13.5 nV/√Hz.**

Figure 5 shows the correct baseline noise density across most frequencies. However, susceptibility to external noise sources becomes apparent even with a rudimentary measurement setup.

Both power line noise (at 50/60 Hz) and higher frequency radiated noise (at 25 kHz and above) show up as aberrations on this ultra-low noise baseline. Identifying and attenuating significant noise source issues at this stage of the measurement system setup is of paramount importance. Adding more equipment to the system will add to this baseline noise.

Figure 5: Pre-Amp 10 kΩ Resistor

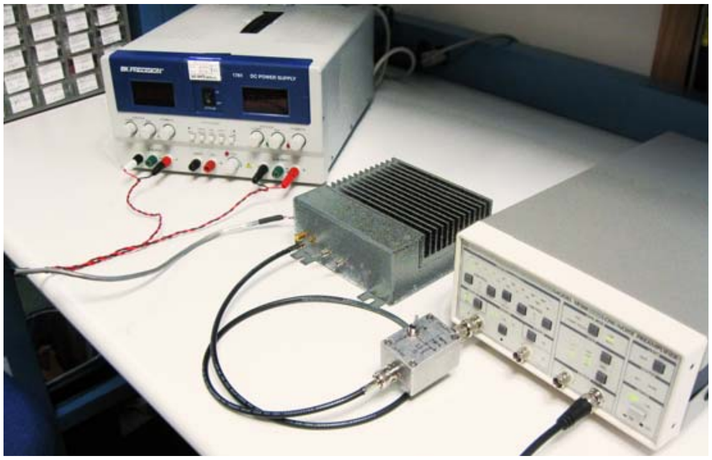


Once the measurement system is verified, add the un-powered QCL driver to the system. We use a 12-inch RG-58 coaxial cable to connect the QCL output to the pre-amplifier input. **Do not add the 20-pin cable or the Analog Input SMA cable yet.** The noise floor of these three components should be the same 4 nV/√Hz. Using the front panel SMA connection, as opposed to the 20-pin connection ensures adequate shielding between the QCL driver and the load. However, radiated noise is still an issue with this low noise configuration. Try wrapping a hand around the coaxial cable. The noise level may rise noticeably.

In the next step, connect the DC power supply to the QCL driver through the 20-pin header but continue to leave the system powered down. Noise levels should be very close to the previous test. The additional cabling of the power supply allows another path for noise introduction, so watch for problems here.

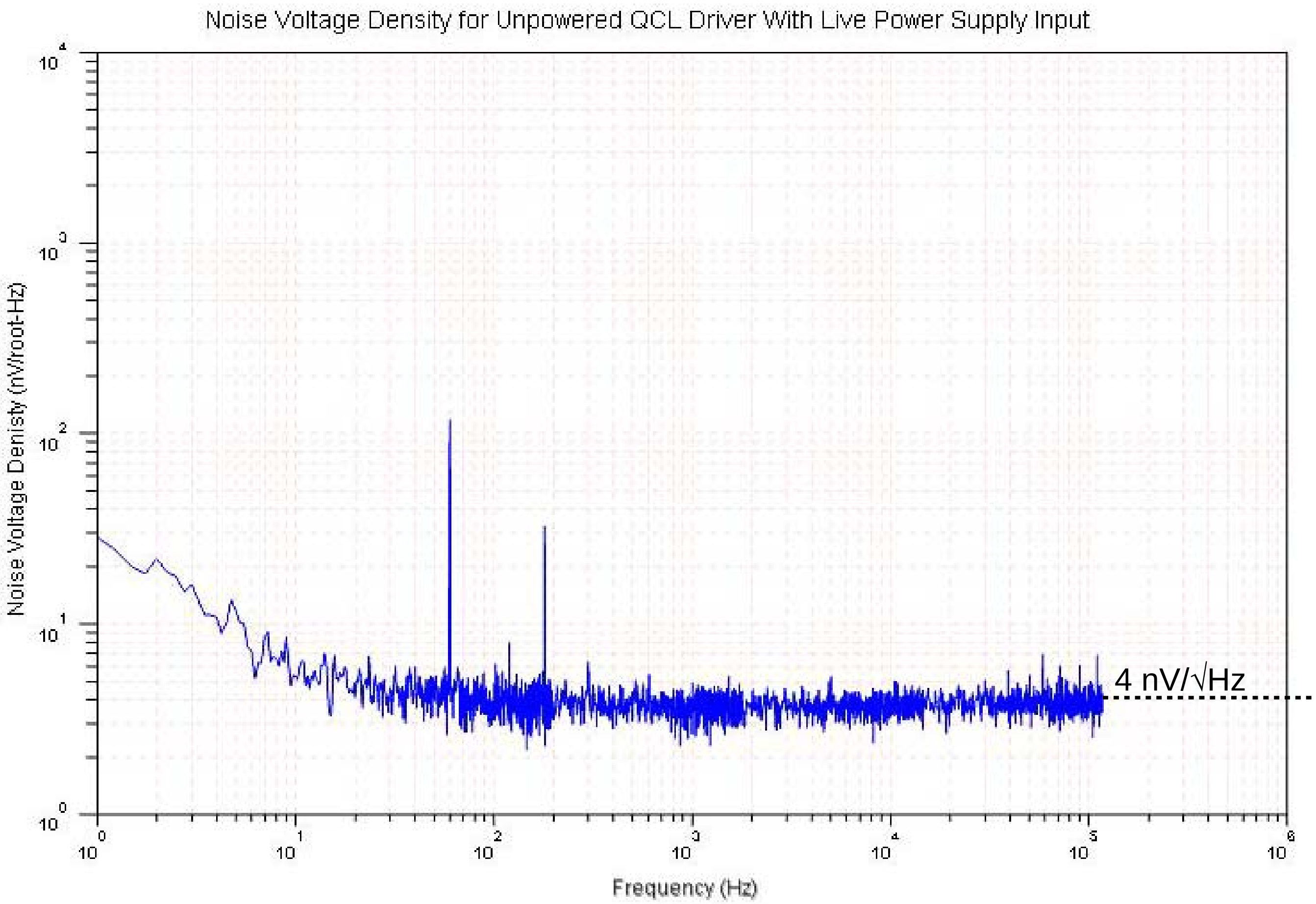
In our system, the power supply is a BK Precision 1761 linear supply and the power cables are 3-foot twisted pairs. These twisted pairs terminate at the QCL driver with a 3-pin cable / connector (WEI #WCB300).

Figure 6: Power Supply & Cabling



After verifying the noise levels with the power supply and driver off, turn on the power supply. The envelope of the system noise should remain at its low level, but significant conducted power line noise may start to appear. This noise appears as spikes at 50/60 Hz and its harmonics. If using a switch mode power supply, switching frequencies may appear in addition to the AC power line noise. This will vary with your wiring and configuration.

Figure 7: QCL Driver and Power Supply



Next, install the test load (WEI #QCLTESTLOAD) to the QCL driver's SMA output. A BNC "T" adapter is required to connect the pre-amplifer across the test load.

Figure 8: Connect Pre-Amp Across Test Load

Power up the QCL driver and enable the output. Adjust the output current to the required level. Noise measurements at this point should match the results posted in the datasheet.

Figure 9:

Model	Average Current Noise Density - nA / √Hz	RMS noise µA (100 kHz BW)
QCL500	1.0	0.4
QCL1000	2.0	0.7
QCL1500	3.0	1.0
QCL2000	4.0	1.3

To calculate noise current density, take the noise voltage density shown on the spectrum analyzer and divide by the load resistance.

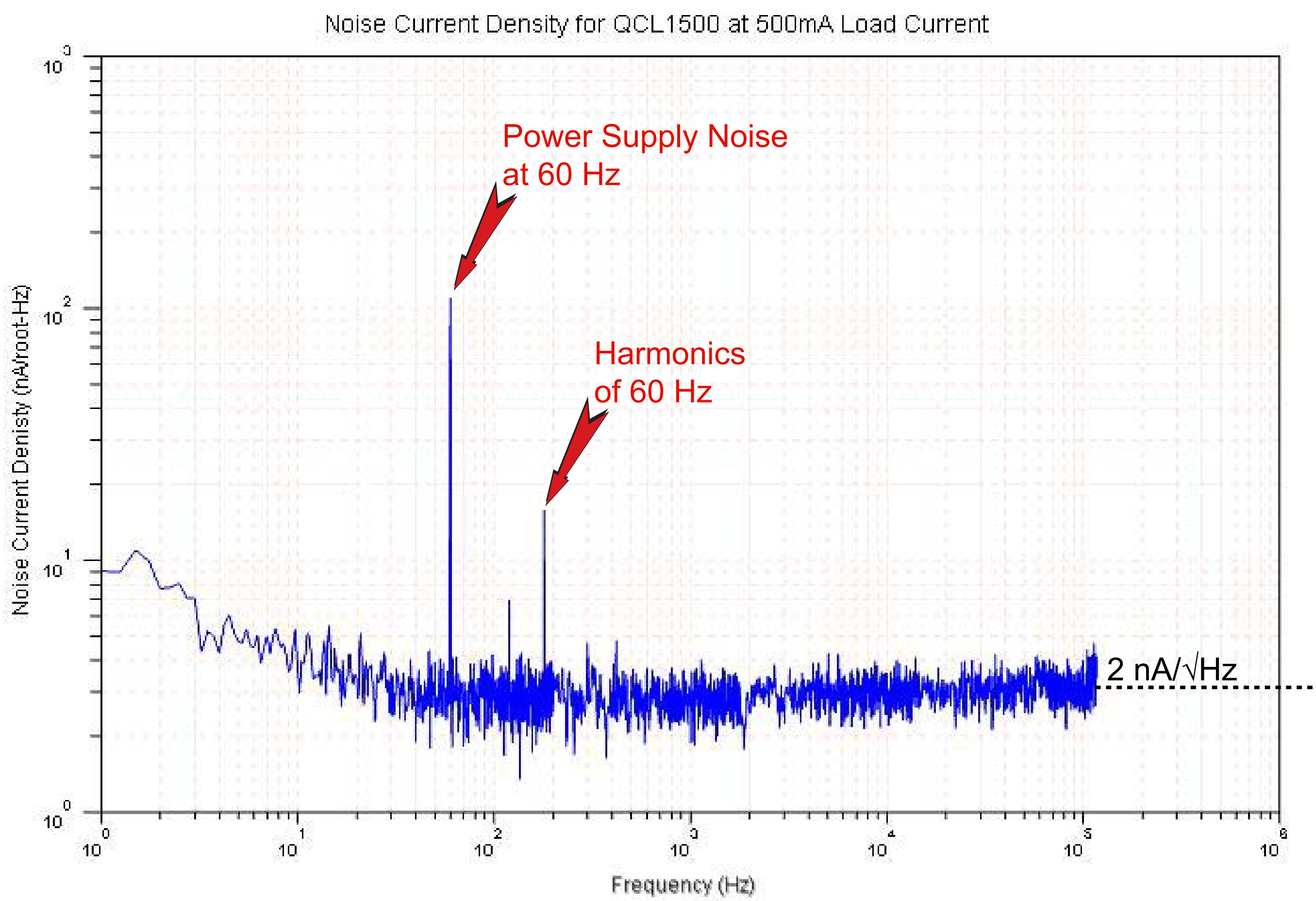
In the Wavelength Electronics test load, we use 10 Ω for low current QCL drivers (QCL500 & QCL1000) and 5 Ω for high current QCL drivers (QCL1500 & QCL2000).

In general, use the following equation for the calculation:

$$\frac{\text{Voltage Noise Density}}{\text{Resistance}} = \text{Current Noise Density}$$

$$\frac{\text{nV}/\sqrt{\text{Hz}}}{\text{R}} = \text{nA}/\sqrt{\text{Hz}}$$

Figure 10: QCL Driver with 500 mA Output



KEY ELEMENT: REMOTE ANALOG INPUT

At this point, additional components can be added to the signal path. Typically, a function generator connects to the remote Analog Input. Any noise inherent in components connected to the remote Analog Input transfer directly to the QCL driver output. The old adage of “Garbage in equals garbage out” holds true for the this high bandwidth input. The input-referred noise of the QCL driver’s remote Analog Input is as low as the internal set point. Noisy sources guarantee noisy outputs.

Figure 11 shows the noise added to the system by a noisy benchtop function generator connected to the external Analog Input. The QCL output noise shows a significant amount of discrete noise current spikes. When compared to the noise of the function generator alone, Figure 12, the noise source becomes apparent. The two noise profiles look strikingly similar. Using a low noise generator at the remote input is an absolute requirement for low system noise.

Figure 11: QCL with Noisy Function Generator

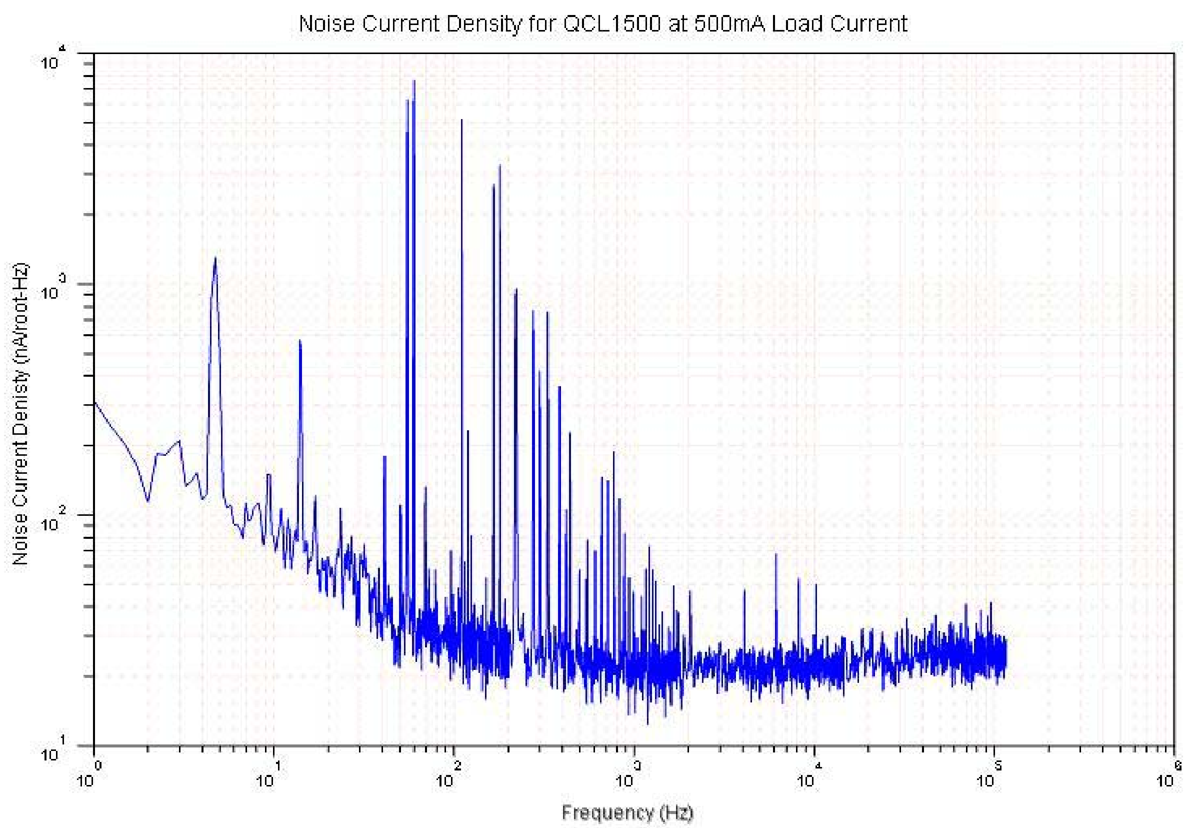


Figure 12: Noisy Function Generator Only

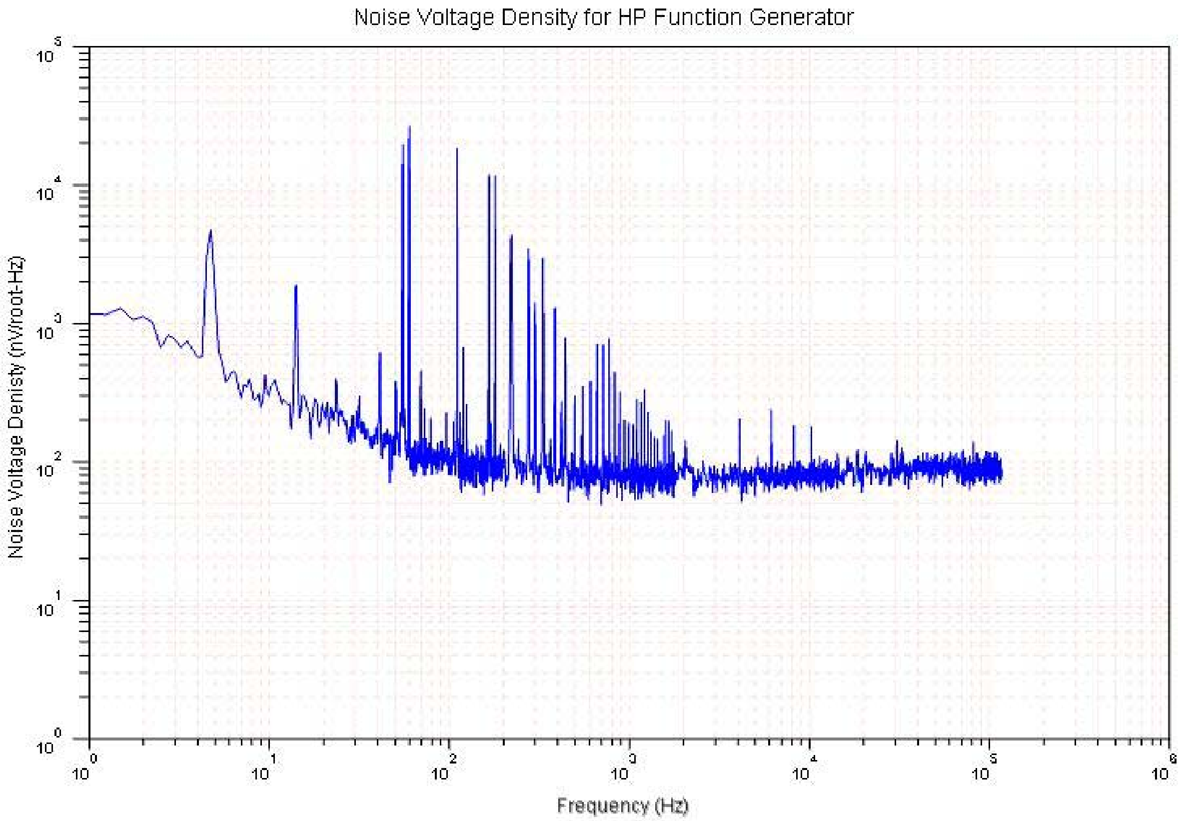


Figure 13 shows the noise profile obtained using a source with less noise connected to the remote Analog Input. The QCL output current here is equivalent, at 500 mA. The exact same behavior occurs in this case. The excess noise of the source passes on directly to the noise profile of the QCL driver's current output.

Figure 14 shows that individually, this function generator produces much less discrete frequency content than the noisy function generator. However, this source still produces noise in excess of the QCL driver's internal setpoint and will therefore dictate the final output current noise. Reaching the full low-noise potential of the QCL driver requires extremely careful selection of remote sources.

Figure 13: QCL Driver with Quiet Function Generator

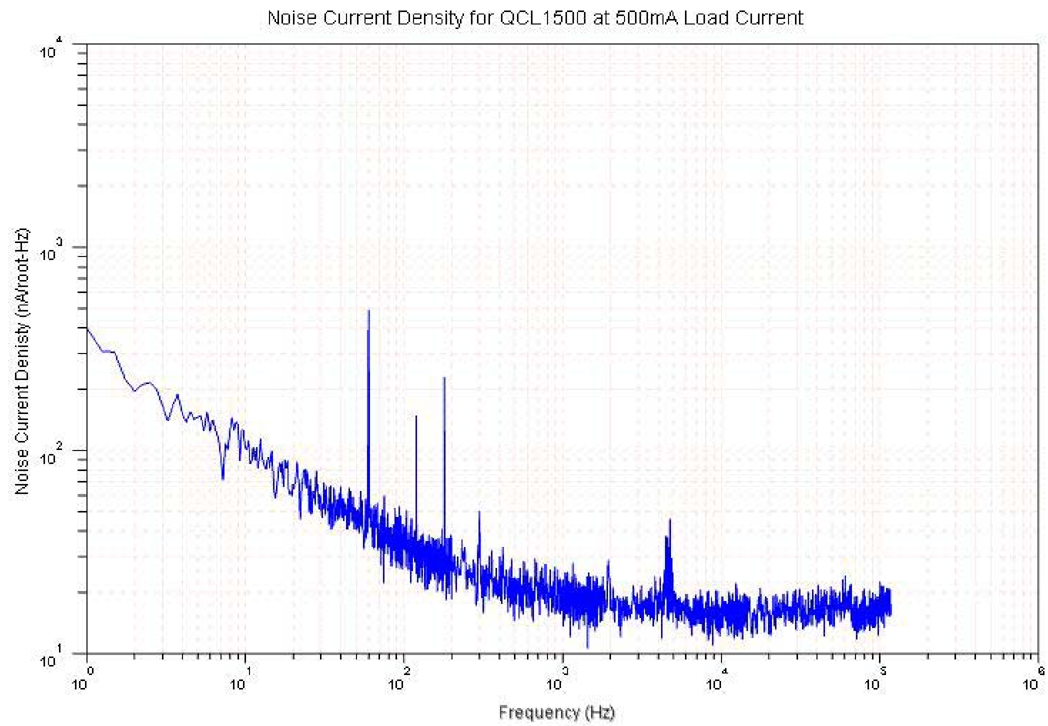
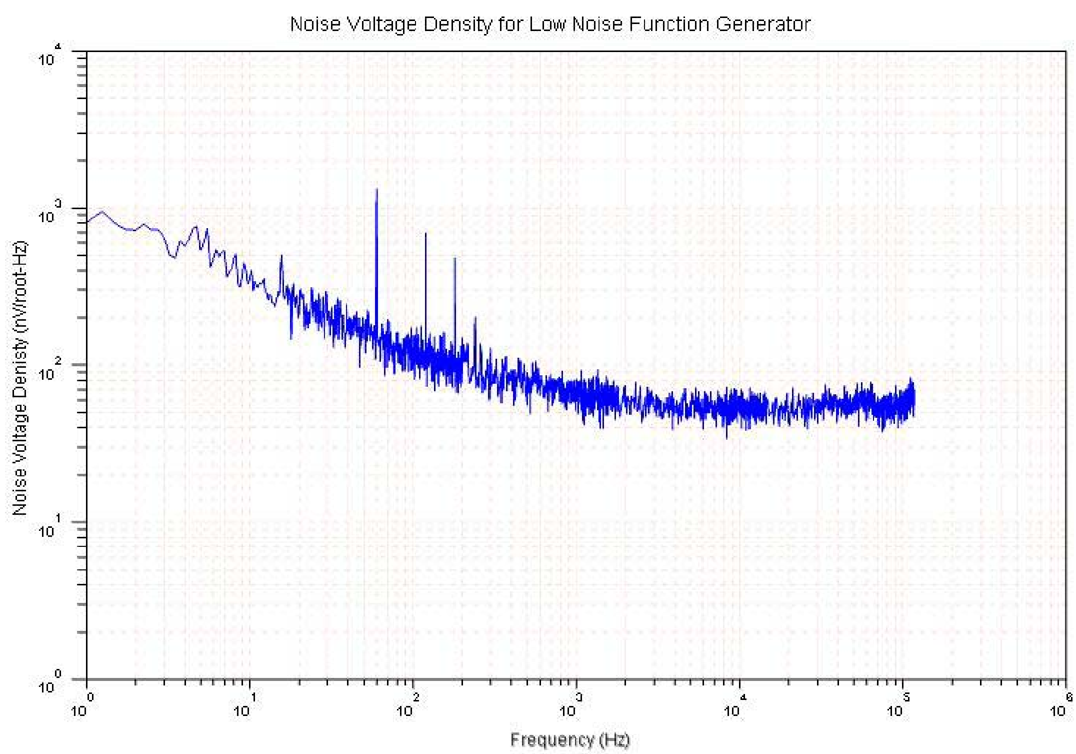


Figure 14: Quiet Function Generator Only



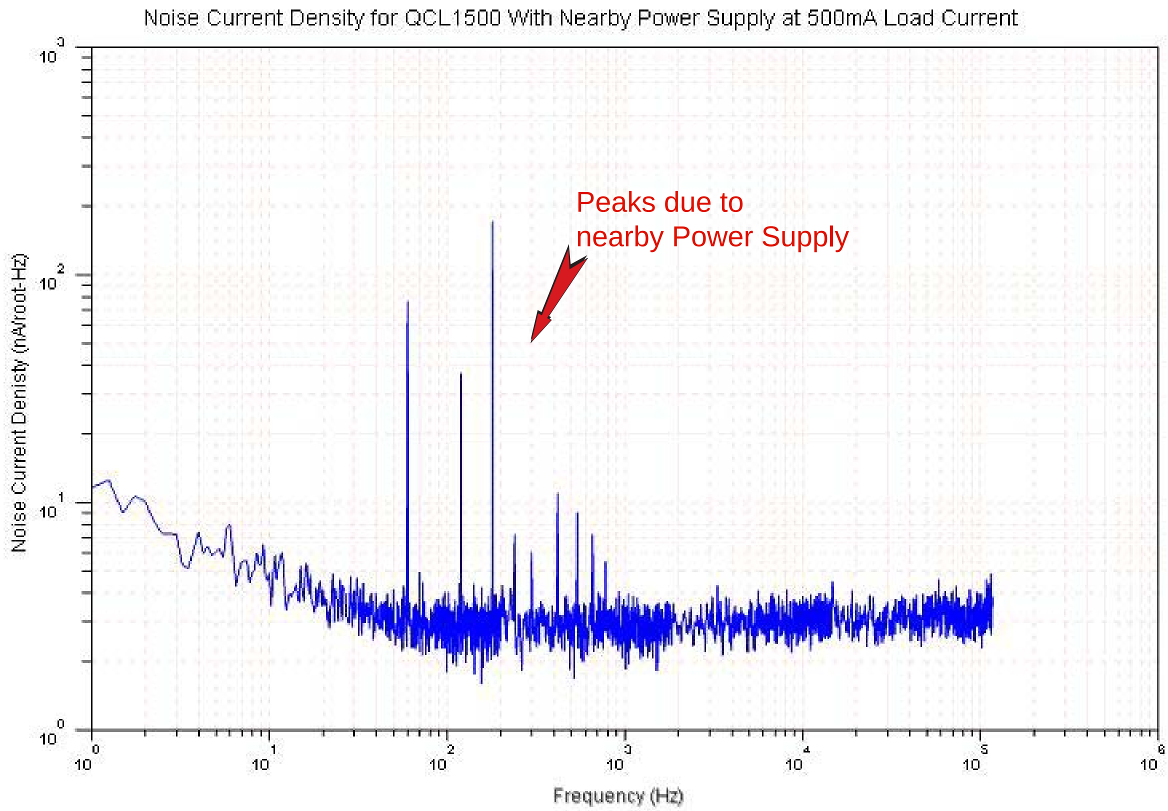
COMMON NOISE SOURCES

Conducted and radiated noise sources exist all throughout the lab and must be dealt with to achieve the lowest possible noise. Ground loop creation commonly wreaks havoc on low noise systems. Always be aware of the overall grounding scheme when measuring low noise systems. Keep all earth grounded AC power cable connections physically close to each other.

Measurement system components can also interact with each other. A sensitive pre-amplifier may be susceptible to fan noise from a power supply when in close proximity. Physical isolation may be the only viable solution, short of large amounts of shielding.

For example, Figure 15 shows the effects of a power supply fan on the noise measurement system at Wavelength Electronics. The noise radiated by a small fan in an unshielded chassis has consequences!

Figure 15: QCL with Nearby Power Supply



Far field electromagnetic radiation can also sabotage low noise measurements. Radio and TV broadcast signals can couple into low noise systems. Shielding and proper grounding reduce this coupling effect.

Connecting a computer to the measurement system often causes deleterious effects on low noise performance. Computer grounds are notoriously noisy. Special isolation techniques, such as optical isolation or transformer coupling, may be necessary with a computer connection.

If the noise at frequencies lower than 10 Hz is higher than expected, inadvertent circuit resistances may be the culprit.

Check connectors and solder joints. Air currents across the load resistor or other circuitry outside the QCL driver also show up as low frequency noise.

Unfortunately, any piece of equipment in the lab that moves electrons will radiate electromagnetic fields and can be a source of noise. Before the advent of the low noise QCL drivers, many sources were masked. Now small noise sources matter.

To find the noise source, turn off or disconnect potential sources, rewire ground lines to find accidental loops, watching the noise floor for changes.

ELIMINATING NOISE SOURCES

This is usually an empirical, qualitative bit of trial and error. Here are three sources of noise and potential solutions:

Higher frequency, radiative noise: Proper shielding with a mu metal or ferrous metal attenuates or eliminates this type of radiation. Depending on the frequency, aluminum might work. Shielded coaxial and twisted pair cables also aid in reducing susceptibility to high frequency EMI. Again, an excellent resource for shielding suggestions is *Noise Reduction Techniques in Electronic Systems*, 2nd Edition (Wiley, New York, 1988), Henry W Ott.

60 / 50 Hz Power Line Noise: This is highly dependent on your choice of power supply and cabling. Decoupling power supply voltages is always good practice. R-C and L-C circuits are an effective way to prevent unwanted power supply noise from entering the low noise system.

Ground loops: Eliminate any loops or at least reduce the physical loop area. See the Wavelength Electronics Application Note *AN-LD08 Manage Grounding to Minimize Noise with the QCL Drivers* for more information. It is also available online:

http://www.teamwavelength.com/downloads/notes/an-ld08.pdf#page=1

TECHNICAL ASSISTANCE

At Wavelength, we want you to get the best noise performance possible. Our Applications Engineers are available to help you troubleshoot. Send us photos of your system and graphs of your noise floor without anything hooked up and we'll help you walk through troubleshooting.

REVISION HISTORY

REV	DATE	NOTES
A	14-Mar-11	Initial Release

KEYWORDS

low noise testing, quantum cascade laser noise testing, high frequency noise, radiative noise, power line noise, system noise analysis, qcl driver troubleshooting, QCL500, QCL1000, QCL1500, QCL2000