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Measuring and Reducing Noise Using an LDX-3620B Ultra Low Noise Laser Diode Current Source

APPLICATION NOTE

ILX Lightwave

Photonic Test and Measurement

Introduction

Noise is an unavoidable characteristic of all electrical circuits, but noise can be minimized with good design, high manufacturing quality, and sound components.

There are three measurements commonly used to characterize the noise of an instrument. The measurements are rms current noise, noise spectral density, and relative intensity noise (RIN). These measurements are explained in the second section.

ILX Lightwave specifies the noise and ripple of every instrument with an rms current noise measurement. The purpose of this application note is to describe the procedure that is used to test the noise performance of our instruments and to demonstrate the effects of seemingly unimportant setup characteristics on the noise performance.

Background

1. Types of Noise

Noise, in electrical circuits, is understood to be an unavoidable signal which does not convey any useful information. It is compiled of random signals that obscure informative data. Noise in a system can be generated internally or introduced by external sources.

The three most common types of noise are Johnson, shot, and flicker. Johnson noise, or thermal noise as it is often called, is generated internally by the random flow of charge in measurement and control systems. Johnson noise is independent of the applied voltage and it has a flat frequency spectrum. This means that the power spectral density is constant throughout the spectrum. Johnson noise also obeys a Gaussian amplitude distribution.

Shot noise is also internally generated and is the result of fluctuations in the current by charges that act independently. While shot is generated by the flow of charge across a barrier, the noise generated by the flow of charge across a metallic conductor or through a standard circuit that provides negative feedback is not classified as shot noise. Shot noise is similar to Johnson noise in that it too has a flat frequency spectrum and obeys a Gaussian amplitude distribution.

Flicker noise is a low frequency phenomenon described by equation [1].

$$I_{\text{flicker}} = \frac{1}{f} \qquad [1]$$

Flicker noise can be introduced to a system by mechanical coupling or coupling in the surrounding electromagnetic field. It can also be generated internally by the power supply or the digital circuitry.

One cause of flicker noise that is pertinent to the noise testing of the LDX-3620B is the triboelectric effect. It is a type of contact electrification where an effected material becomes electrically charged because it rubs against another material and is subsequently separated. The electrical charge generates noise.

Flicker noise can be reduced by a well designed and carefully manufactured circuit of high quality components, but Johnson and shot noise are unavoidable and irreducible forms of noise.

Though these three types of noise are the most common, they are not the only forms of noise present in circuits.

2. Types of Measurements

An rms current noise measurement is frequently used to describe the noise performance of instruments used in test and measurement applications. The rms current noise is the root mean square of the average noise in the output over a specified frequency spectrum. This measurement is a single value, as opposed to a graph, which makes the comparison of instrument specifications simple. The noise of all ILX Lightwave current sources is described by the rms current noise. A detailed description of the setup and test procedure to measure the rms current noise is in the third section.

The noise spectral density is another often used measurement. The general setup used to measure the noise density is depicted in Figure 1.

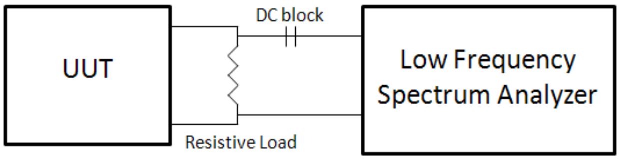

FIGURE. 1: The general setup that is used to measure the noise spectral density. The DC block prevents DC current from entering the spectrum analyzer.

The result of noise spectral density testing is a graph showing the noise at every frequency. Since the value of measured noise is dependent on the bandwidth over which the measurement is taken, the noise spectral density is easily manipulated. A narrow bandwidth can be thought of as a keyhole, through which only a small amount can be seen, whereas a broad bandwidth is similar to an open door.

ILX Lightwave does not describe noise by the noise spectral density because the result cannot easily be compared to similar instruments and the data is easily manipulated.

The last noise measurement technique that we will discuss in this application note is the relative intensity noise or RIN. The test is purely optical and is a measurement of phase noise. The result is a graph of electrical noise power spectral density versus optical power. Figure 2 shows a general setup for measuring RIN.

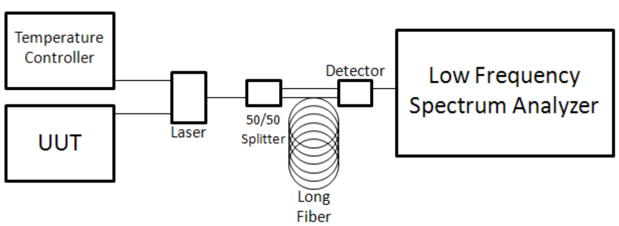

FIGURE 2: The general setup that is used to measure relative intensity noise (RIN). The length of the long fiber from the splitter is dependent on the frequency spectrum at which the user wishes to look.

The RIN is not measured at ILX Lightwave because the results are not repeatable. The measurement is dependent on the specific laser used. Due to wear or damage to the original laser, a laser of similar specifications will be substituted in the setup and the measurement will change slightly.

Test Setup

1. Grounding

Proper grounding is the single most important element of noise testing. Improper grounding can cause signal coupling on the grounding path which can overshadow the noise source signals and cause false noise in the system. The key to proper grounding is to ensure that the current flowing through a ground line does not generate a noise signal that is detected by another part of the system sharing a common ground.

Grounding instruments to different grounding planes is an example of incorrect grounding. Though noise is undoubtedly present, incorrect grounding will cause a false, elevated noise measurement.

2. Loads and Connecting Cables

When measuring the rms current noise, the test load is a non-wire-wound resistor mounted on a heat sink and covered by a connector plate. The shielding plate forms a Faraday cage that prevents high frequency noise from entering the system. For current sources that supply less than 500mA of current, the test load is 24Ω. Sources that supply more than 500mA use a 1Ω test load.

The noise created by long wires and coiled cables is the second most important factor to noise testing. Noise signals are so small that they are easily drowned out by the noise generated by the resistance, capacitance, inductance, and grounding signals in the connecting cables.

3. The Setup

Proper grounding was achieved by placing the setup on a conductive metal plate. All instruments were grounded at a single point on the plate. All overhead lights were turned off and other instruments were moved more than three feet from the LDX-3620B, unless otherwise specified, to minimize the high frequency noise introduced to the system.

The LDX-3620B was connected to the test load via a 6-inch shielded cable unless otherwise stated in the test condition. Three additional cables were tested the CC-305S Current Source/Laser Diode Mount Interconnect Cable, CC-306S Current Source/Unterminated Interconnect Cable and a homemade cable.

A CC-305S cable is well-shielded and terminated at both ends with male 9-pin d-subminiature connectors. The CC-306S cable is also well-shielded, but it is only terminated at one end. The homemade cable was the same length as the CC-305S and the CC-306S, but was made of five wires that were not shielded; the wires were twisted and taped together at twelve inch intervals. The connecting cable used depended on the test condition requirements.

The voltage drop across the load was measured by a Signal Recovery 5184 Ultra Low Noise Preamplifier. The preamplifier provided a gain of 1000 and a constant upper bandwidth limit of 1 MHz. The preamplifier was set to operate on battery power and the isolation switch was set to ground.

The noise signal was passed by BNC cable to a Tektronix ADA400A Active Differential Preamplifier. The second gain stage provided a gain of 100. The two gain stages were necessary to detect the minute noise signal.

The signal was then passed by BNC to a Tektronix TDS3014 Oscilloscope with 1MΩ impedance. The rms voltage of the signal was measured in mV.

The gain from the Tektronix differential preamplifier was omitted in the noise calculations because it was accounted for in the rms voltage measurement on the Tektronix oscilloscope. The test setup is depicted in Figure 3.

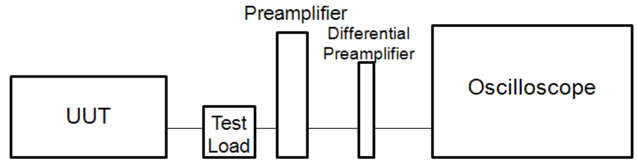

FIGURE 3: The setup used to measure rms current noise. The unit-under-test (UUT) is the LDX-3620B Ultra-low Noise Current Source.

4. The Procedure

The rms current noise floor, $I_{noise\ floor}$, must first be determined prior to calculating the rms current noise of the current source. $I_{noise\ floor}$ is the minimum amount of noise achievable in the setup. It is important to attain the lowest noise floor possible to accurately measure the noise of the current source.

To measure the noise floor the LDX-3620B was powered on in I_{LBW} and battery mode, but the output was not enabled. The load was disconnected from the unit-under-test (UUT) to calculate the rms current noise floor. $I_{noise\ floor}$ was calculated by dividing the highest rms noise voltage reading seen on the oscilloscope, V_{rms}, by the preamplifier gain, G, and the resistance of the test load, R_{LOAD}.

$$I_{noisefloor} = \frac{V_{rms}}{G \cdot R_{Load}} \quad [2]$$

The gain was 1000 and the resistive load was measured at 23.965Ω.

After the rms current noise floor was determined, the test load was reconnected to the UUT and the output was enabled in the 200mA output range with the current set at 100mA. The upper bandwidth of the differential preamplifier was set to 100Hz. The maximum rms noise voltage reading on the oscilloscope was recorded for each Test Condition. The upper bandwidth of the differential preamplifier was changed to 100kHz and the maximum rms voltage reading was recorded.

The process above was repeated in the 500mA output range with a 250mA set point.

The rms current noise was calculated by dividing the maximum rms voltage reading by the gain times the load resistance and subtracting the calculated current noise floor.

$$I_{noise} = \frac{V_{rms}}{G \cdot R_{Load}} - I_{noisefloor} \qquad [3]$$

5. Testing Conditions

The effects of the following setup conditions on the noise performance of the LDX-3620B were tested.

Test Condition 1: The rms current noise was measured with a well-shielded, 6-inch cable connecting the instrument to the load **(a)** just after the LDX-3620B was powered on and **(b)** after a one hour warm up period.

Unless otherwise stated the remaining test conditions used a LDX-3620B that had warmed up for at least one hour.

Test Condition 2: The LDX-3620B was connected to the test load via **(a)** a neatly coiled CC-305S, **(b)** an uncoiled, unsecured CC-305S and **(c)** an uncoiled CC-305S that was secured to the table.

Test Condition 3: The LDX-3620B was connected to the test load via a homemade cable.

Test Condition 4: The LDX-3620B was connected to the test load via CC-306S, which was soldered by the user to a 9-pin connector.

Test Condition 5: An ILX Lightwave LDT-5980 Precision Laser Diode Temperature Controller with the output enabled was **(a)** placed on top of the LDX-3620B and **(b)** more than three feet away. The 6-inch connection cable was used.

Test Condition 6: An ILX Lightwave LDT-5525B Laser Diode Temperature Controller with the output enabled was **(a)** placed on top of the LDX-3620B and **(b)** more than three feet away. The 6-inch cable was used.

Test Condition 7: Both modulation ports were set to accept alternate current on the LDX-3620B. The 6-inch cable was used.

Test Condition 8: (a) A powered up function generator was connected to the coarse modulation input port of the LDX-3620B and the port was set to accept AC current. The fine modulation input port remained disabled.

(b) Noise was also measured with both modulation ports turned off, but with the function generator still powered on and connected to the coarse modulation input port. The 6-inch connection cable was used.

Results

The noise floor for each range and frequency spectrum, calculated using equation [2], are listed below in Table 1.

Noise Floor (nA)	*100Hz*	*100kHz*
200mA Range	8.9	16.6
500mA Range	9.3	17.5

Table 1: The noise floor at half-scale in each range was calculated over a 100Hz spectrum and a 100kHz spectrum.

The rms current noise values listed in Table 2 were calculated using equation [3], which subtracts the rms current noise floor from the rms current noise measurement.

Table 2 lists the rms current noise of Test Conditions 1 through 9 in comparison to Test Condition 2(c).

The rms current noise for Test Condition 2(c) was 27.5nA and 38.0nA in the 200mA current range measured over a frequency spectrum of 100Hz and 100kHz, respectively and 64.1nA and 93.1nA in the 500mA current range measured over a frequency spectrum of 100Hz and 100kHz, respectively.

Test Conditions	Measured Noise (nA)			
Current Range	*200mA Range*		*500mA Range*	
Frequency Spectrum	*100 Hz*	*100k Hz*	*100 Hz*	*100k Hz*
Test Condition 1(a)	32.5	29.2	20.8	43.9
Test Condition 1(b)	6.6	2.5	7.1	19.9
Test Condition 2(a)	10.8	16.7	11.7	18.9
Test Condition 2(b)	5.8	1.8	5.8	16.9
Test Condition 2(c)	0	0	0	0
Test Condition 3	17.0	63.0	47.9	55.9
Test Condition 4	7.4	12.9	7.9	39.9
Test Condition 5(a)	10.8	5.9	36.9	24.9
Test Condition 5(b)	7.8	1.3	25.4	20.9
Test Condition 6(a)	68.3	21	210	394
Test Condition 6(b)	37.5	35.1	36.9	65.9
Test Condition 7	96.5	132	128	270
Test Condition 8(a)	97.5	124	310	306
Test Condition 8(b)	57.1	58.8	108	207

Table 2: The rms current noise values of the current output of the LDX-3620B in comparison to Test Condition 2(c). The testing conditions are listed in Section 3.

Test Condition 1 demonstrated the importance of the one hour warm up period to the noise performance of the LDX-3620B. An instrument that is used immediately after turning on will have, on average, four times more noise than an instrument that is allowed to warm up for one hour.

When the cable is coiled into a neat coil as in test 2a, it generates flicker noise because the coil acts as an inductor. As test condition 2b showed, when the cable is uncoiled and laid flat, the noise is reduced by more than half. However, the best noise performance is achieved when the cable is secured to the table (test condition 2c), which reduces the triboelectric effect.

Test Condition 3 demonstrated the importance of a shielded cable to the noise performance of any instrument. The homemade cable introduced up to 63nA of noise to the system.

Test Condition 4 showed that while the CC-306S offers the customer more flexibility, exposing the tips of the wires to the environment introduced up to 39.9nA of noise.

The close proximity of an operating instrument also introduces noise, as proved by Test Conditions 5 and 6; however, the type of power supply in the nearby instrument is not directly related to the noise. The LDT-5525B uses a linear power supply that generates less output current noise then LDT-5980 that uses a switch mode power supply. However the LDT-5980 radiates less noise because of the improved shielding of the switch mode power supply.

When the LDT-5545B and the LDT-5980 were placed more than three feet away from the LDX-3620B, the noise introduced by the temperature controllers is still present, but reduced.

The modulation input ports act as antennae for noise when they were turned on. The act of switching the modulation ports off creates a short across the inputs. As the data for Test Condition 7 shows, an enabled modulation port introduced up to 270nA of noise.

When a function generator was connected to the modulation port and only the connected modulation port was switched on, up to 306nA of noise was introduced. If both ports are turned off, up to 207nA of noise was introduced.

Conclusion

Current noise is easily introduced into laser diode tests, but with care during setup the noise can be drastically reduced. For optimal noise performance with the LDX-3620B the instrument should be warmed up for one hour prior to testing and configured for battery operation in I_{LBW} with the modulation ports set to off. The connection to the laser diode should be well shielded and the cable secured to the table. Additional instruments should remain at a minimum of three feet from the LDX-3620B and if possible the overhead lights should be turned off. Also when looking for the source of noise in your setup, look outside of the instrument. Noise will be generated in such places as the orientation of cables, cable type, and grounding paths.

The published rms current noise specification for the LDX-3620B is listed in table 3. The results in table 2 were determined with a single instrument and are not guaranteed.

Measured Noise (nA)	*100Hz*	*100kHz*
200mA Range	<70	<120
500mA Range	<250	<400

Table 3: The published rms current noise values taken from the LDX-3620B brochure.

References

1. D. Pozar, "Active Microwave Circuits", Microwave Engineering, 548-559 (1998).
2. P. Horowitz, W. Hill, "Precision Circuits and Low-noise Techniques", The Art of Electronics, 430-438, 449-461 (2008).

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