Neuralynx ~ TechTips

Noise Debug 101 - Introduction

Noise is any unwanted signal that contaminates your desired signal. It may originate internally from other bioelectric signals or externally from any voltage or magnetic energy source. There are many external noise sources from our high-tech world, many of which are generated by necessary technology such as computers and AC wall power. The challenge for neuroscience researchers is to find solutions that reduce or eliminate the noise source or reduce the coupling of the noise into the recording setup.

Magnitude of Signals

The challenge of noise in the electrophysiology environment is the magnitude of the desired signals from the brain (microvolts to millivolts) to the external noise sources (hundreds of volts) in the laboratory environment. This represents a "100 Million to One" ratio of desired signals to noise sources.

The good news is that noise signals can be greatly reduced or entirely eliminated through proper identification and coupling reduction techniques! Part 5 of this series will cover recording techniques used to eliminate noise signals on our electrophysiology data.

Key Electrical Engineering Concepts & Terms

1. A signal (current) always flows in a complete loop. It is important to keep the "loops" in mind when analyzing the source of the noise and how it is coupled into your recording circuit. The total voltage drop around a loop is always ZERO.
2. Whenever current flows through a conductor, there is a voltage drop because every conductor has resistance.
3. Ohm's Law is key to this discussion: V = I * R Voltage drop = Current times Resistance.
4. Changing signals (AC signals other than static DC values) will be conducted by capacitance as well as by conductors; there is capacitance between any two metal objects anywhere in space. The higher the frequency of the noise, the better it will be conducted by capacitance.
5. A changing magnetic field will induce a voltage and current flow into a conductor, single wire or a loop of "turns." The magnitude of the induced signal is based on the number of turns in the loop and the area of the loop.
6. Ground is not absolute! There is no such thing as a "perfect earth ground." Ground is only a point where measured voltages are relative to: you can measure significant voltages between two different close locations in the earth.
7. Voltage drops in a circuit (loop) are based on the ratio of component impedances of each component.
8. Impedance and Resistance are very similar: Resistance is for "steady state" DC circuit analysis; and Impedance is for the AC frequency circuit analysis. Both are measured in Ohms, but impedance has an

"imaginary or complex component" resulting in a "phase shift."

9. The term "Ground Loop" is often misunderstood. When you have an "extra conduction path" around a circuit, it usually does not result in "magnetic coupling into the ground loop" creating current flows and AC power line frequency noise.

Noise "Sherlocking"

When you observe an external noise signal in your recordings, you must first identify the noise source. This is done by observing the signal and answering such questions as:

- Is it at the AC Power Line frequency or a multiple of the frequency?
- Is it dependent on location?
- Is it dependent on a piece of equipment being turned on or plugged in?
- Does you hear anything unique, like music, when listened to?

These will all provide you with clues about the source of the noise.

After you determine the noise source, you need to run some experiments to determine the external coupling type that is causing the noise to "get into your setup." For example, a florescent light has three possible conduction types: electrostatic from the high voltage (120 or 220VAC), magnetic from the turns of wire in the ballast; and RF from the high frequency "sharp edges" of the florescent tube starting and stopping current flow on every ½ cycle of the power line voltage cycles. Note: "Getting out the aluminum foil" for every noise problem usually doesn't work and the "fix" may be rather inconvenient.

Once you identify the source and coupling type, it is usually easy to implement a solution to resolve your noise problem, delivering clean, recorded signals!

Our **Noise Debug 101** series will examine the physics behind each coupling type and the method(s) for designing an experiment that test for its magnitude.

Parts 1-4 address the four main types of external (environment) noise signals:

- Part 1 - Conducted Noise (common path voltage drop)
- Part 2 - Electrostatically Coupled (voltage coupled)
- Part 3 - Magnetically Coupled
- Part 4 - Radio Frequency Coupled
- Part 5 - Practical Noise Abatement

Static Buildup

Static appears in recordings as either “large random pops” when static discharges occur or large wavering low frequency waves when it is accumulating on the subject.

Plastic Mazes and Operant Chambers can cause large static buildup on the animal subject, resulting in recording artifacts, possible damage to equipment and small micro-lesions around the electrode tips, killing close cells. If you wanted to generate static, rub a plastic rod on a furry surface!

To reduce static charges, consider the following:

- Do not use Poly (methyl methacrylate) (PMMA) in mazes. (Also known as Lucite, Plexiglass, acrylic, acrylic glass, Acrylite®, and Perspex®.) These generate static! Use Polycarbonate known as Hyzod®, Calibre™, Ensicar, Makrolon®, Thermocomp™ D, Unicar® and ZL®1600. Polycarbonate is also easier to drill and machine.
- Dental cement is a polymer that can generate static when fur touches it. A small amount of EEG electrode paste applied to the fur/implant area will stop static in this area.
- Use redundant ground-skull screws and make sure they are well connected to the Electrode Interface Board (EIB) ground.
- Use an anti-static spray, such as Staticide® Spray, on the maze/arena before starting an experiment.
- Anti-static arena construction materials include: wood, or wood composites like Melamine; Teflon® and Delrin® type plastics; cardboard; carbon fiber composites or sheet metal.
- Use a small room humidifier to increase the moisture and conductivity of the air, which also reduces the amount of static generated with normal movement.
- ALWAYS WEAR A GROUNDING WRIST STRAP WHEN HANDLING YOUR SUBJECTS (human or animal). A wrist strap has a 1 Megaohm resistor to control static discharge. This should be connected to the PGnd of the recording system.

Grounding to Avoid Conductive Ground Loops

As discussed in Noise Debug 101 - Part 1, grounding is always key. If the subject is in contact with a metal or conductive surface, a “conducted ground loop” may be created and will generate noise. Ground these to the recording system Panel Ground (PGnd) and do not allow any contact with the main building ground, which includes concrete and hard flooring surfaces. Insulate a conductive metal maze from the floor or grounded surface with a non-conductive material such as wood or plastic. As long as the maze is connected to PGnd there will not be any static buildup on the maze.

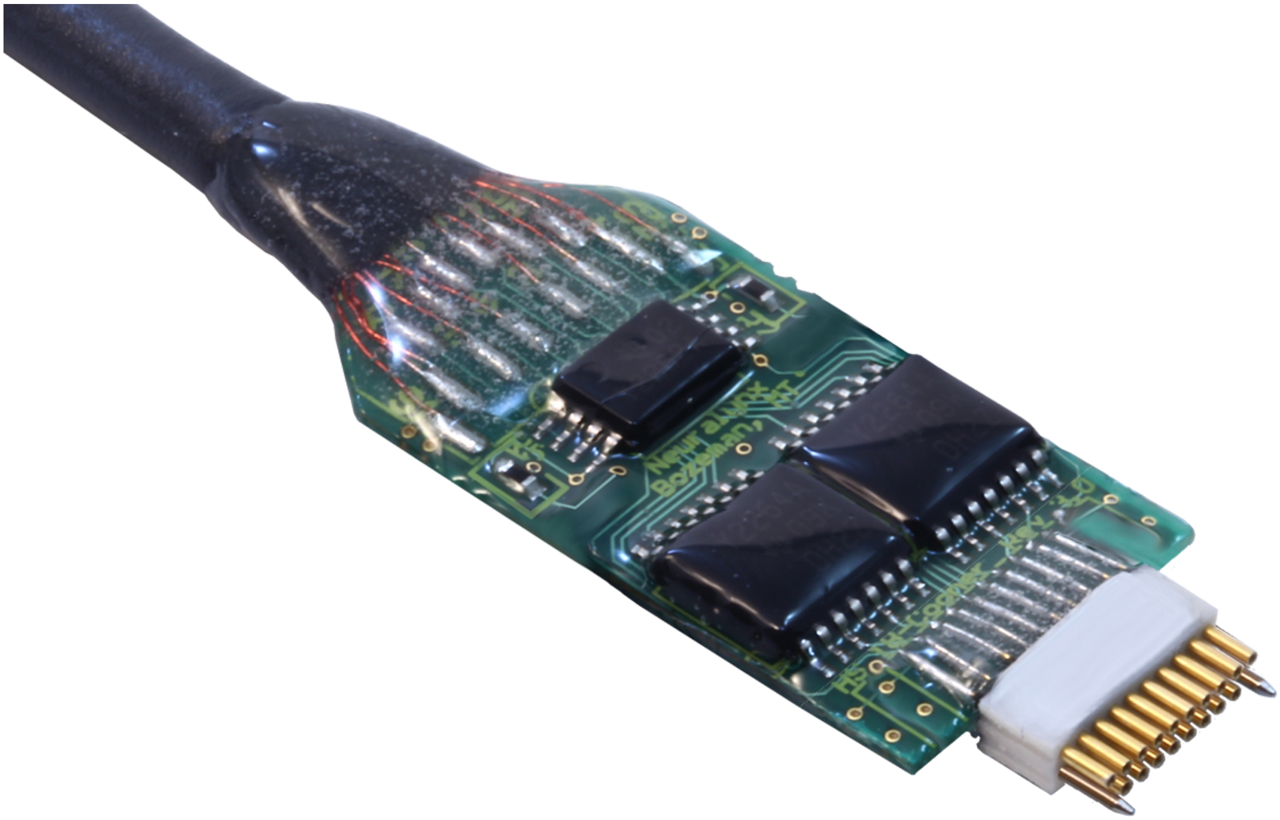
Impedance and Electrostatic Noise Conduction

In Noise Debug-Part 2, we analyzed the paths of electrostatic conduction that cause external noise introduction into the small neural signals. Based on the equations and electrical models, the amount of noise induced into your signals is also based on the impedance of the signal line. Lower impedance signals will be less susceptible to noise induction. This is the reason for using buffered headstage amplifiers on the subject as close to the electrodes as possible. The headstage buffer OpAmp output impedance is between 2 and 20 ohms, compared to the 500 Kohm impedance of a microwire electrode. We participated in experiments using a “good headstage design” (HS-54/27/36) with a 30-meter tether cable with less than 1 microvolt of extra noise!

High impedance signals, such as microwires, should be kept as short as possible and connected to the EIB/headstage as close as possible to the skull. Because the headstage buffer output impedance is very low tether cable routing is not as critical and is more forgiving.

Consistency of microelectrode and reference electrode impedances is important because different impedances will have different amounts of noise induced. And this difference in noise on the signal electrode and reference electrode will not be removed by the system amplifier -regardless of the Common

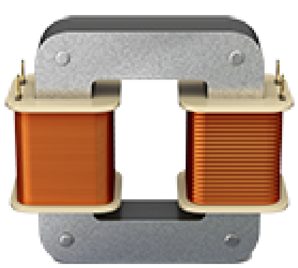
Mode Rejection performance of the system.



Consistency of Headstage Input Impedances

All electrode and reference headstage input impedances must be the same for equal treatment of the signals. Reference electrodes should be buffered by the same high quality OpAmp. The Intan 32 and 64 channel RHDxxx series of IC's have a much lower reference input impedance (32:1) and thus do not give proper reference electrode operation for removing common mode noise signals.

For the recording system to properly subtract the reference input from the electrode inputs, all aspects of all channels must be consistent!



Magnetic Conduction Reduction

We covered the theory of magnetic conduction in Noise Debug-Part 3. The best technique for reducing conduction is to keep the “Loop Area” of signal conductors to a minimum. The loop is between the electrode and reference signals and the return Ground and Power lines of the tether. This is accomplished by having long tether signal cables bundled together in a single cable or by “lacing” the wires and cables together with dental floss. Twisting signal, reference and power wires together also helps. (This may not be possible with commercial cables: You would have to twist or braid all tether wires in a cable - which is not practical.)

If possible, reorienting magnetic noise sources (power supplies) by 90 degrees is very effective.

When high current signals (10 mA or greater other than static DC power) are transmitted down the tether, always use a differential twisted pair to transmit the signal. This has been done with success for delivering stimulus signals down a tether with the Neuralynx headstages and tethers for video tracker LEDs and other on-animal stimulus delivery. This requires a custom tether with the twisted stimulation channel wires.

Shielded Cables

It is always best to use shielded cables for all signals, both low level and high level. This helps reduce electrostatic conduction as explained in Noise Debug-Part 2. Note: Shielding will make a cable stiffer and thicker and may not be desired in animal tethers.

High level digital or communication signals should also be shielded to avoid radiating electrostatic fields. Even slow changing 5-volt digital “TTL” signals have fast signal transitions on the rising and falling edges which create high frequency signals and are conducted (see Part 2).

Other Practical Information

Use of DC lighting: We've seen 12 volt "track lighting" with LEDs used for lighting in the recording room in efforts to reduce noisy AC florescent lights. In reality each LED bulb contains a small high frequency power supply and radiates high frequency noise. The main DC power supply is always a switching power supply design and can also radiate high frequency noise.

Conductive floor wax or conductive epoxy floor paint can be applied in the recording room to eliminate static buildup.

Static conductive Crocs™ brand or gym shoes can be purchased to eliminate static. When combined with a conductive floor surface, these work about as effectively as a wrist strap. This type of shoe is made for electronics manufacturers.

To avoid the "conducted" noise signals between equipment power supplies, plug all equipment in the recording room into a common power strip to avoid differences in ground and AC wall power noise.

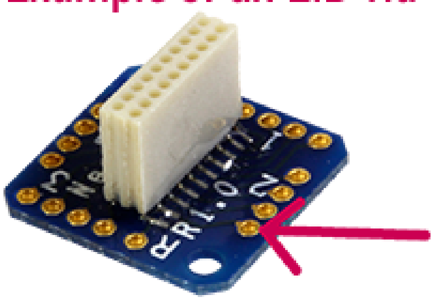
Use of a "power isolation transformer" can be effective in situations where the AC power source is very noisy. These cost about $700 USD and weigh about 20 kg.

The Best Connection Technique to Your Subject

We've discussed grounding, static, shielding and impedances. Now let's tie all of this together for the ultimate connection to the subject for microwire recording:

- Low tetrode electrode impedance – always plate the electrode tips;
- Low reference electrode impedance – always plate the electrode tips;
- Good skull ground connections – use two screws for redundancy;
- Use a Reference electrode placed close to the recording electrodes - a ground skull screw doesn’t make the best reference; it must be in the brain with similar impedance (< 10:1 difference);
- Use a shielded tether cable;
- Keep electrode wires outside the skull as short as possible;
- Shield the microdrive body if possible and connect to the EIB Ground;
- Use a headstage with at least a 100 Gigaohm input impedance;
- Use a headstage with < 5 picoamp leakage current to avoid polarizing the electrodes;
- Use a headstage with identical electrode and reference input characteristics.

Example of an EIB via



Also, the electrode wire to the Electrode Interface Board (EIB) is critical because if it has high impedance or is unreliable, you will see inconsistent recording quality and increased noise. Neuralynx Gold EIB Pins provide the best connection method. These are “micro tacks” that are inserted in the via of the EIB and crimped in place with a strong hold. The connection is very low impedance (~0 ohms), fast to apply, clean and reliable. Most microwires do not need to be stripped because the pin crushes the insulation.

Therefore:

- Use Neuralynx Gold EIB Pins for attaching electrode wires to the Electrode Interface Board (EIB) – best reliability and consistency and you don’t have to “flame strip” the wire connection;
- Don’t solder electrode wires to the EIB – this takes too much time;
- Don’t use silver paint or silver epoxy to attach electrode wires – it is unreliable and messy.