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.

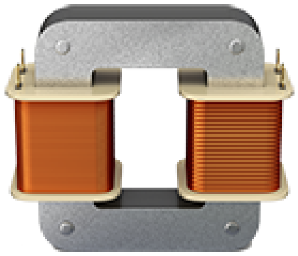
After you determine the noise source, you need to run some experiments to determine the external coupling type that is causing the noise to "get into your setup." For example, a florescent light has three possible conduction types: electrostatic from the high voltage (120 or 220VAC), magnetic from the 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:

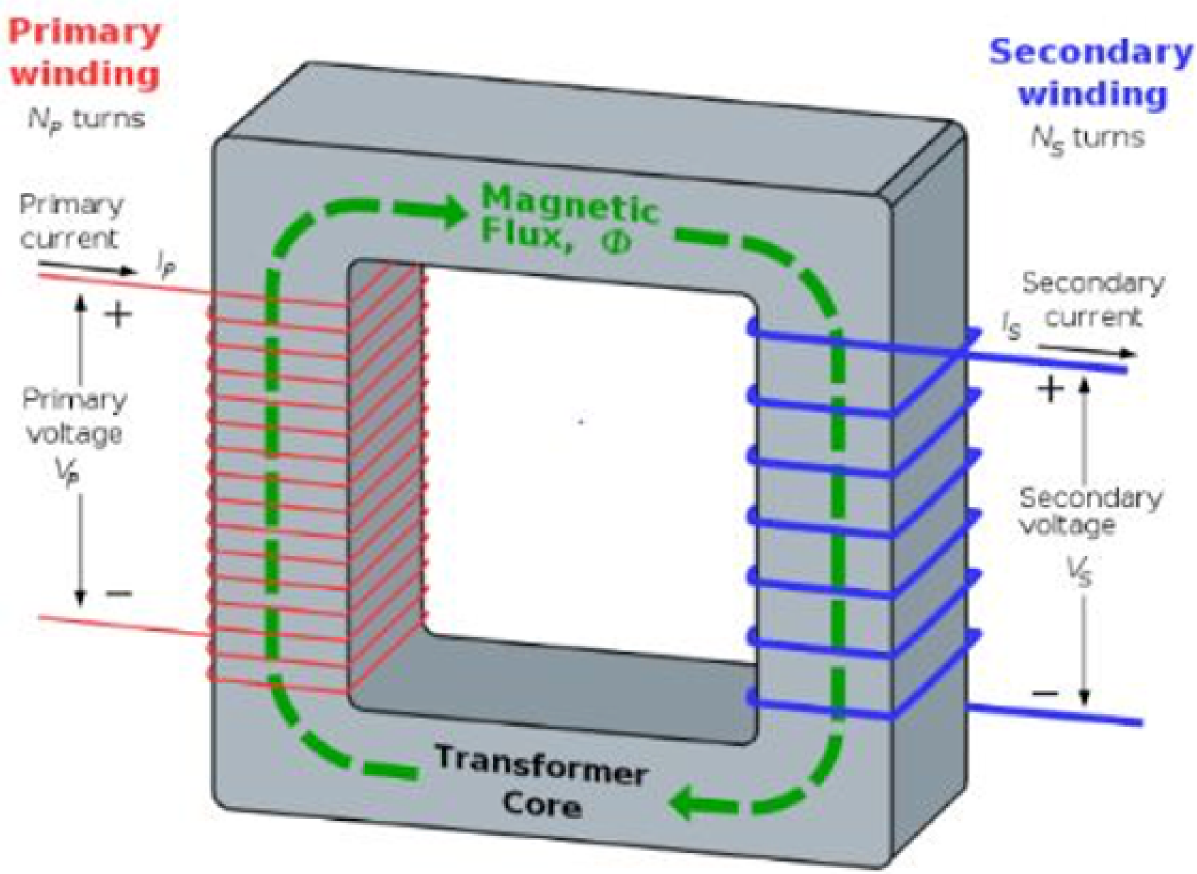
- Part 1 - Conducted Noise (common path voltage drop)
- Part 2 - Electrostatically Coupled (voltage coupled)
- Part 3 - Magnetically Coupled
- Part 4 - Radio Frequency Coupled
- Part 5 - Practical Noise Abatement



Electromagnetic Conduction

Electromagnetic Conduction: The process where a conductor placed in a changing magnetic field (AC) causes the generation of a voltage across the conductor.

Schematic of Electromagnetic Conduction



This coupling type is classified by a changing magnetic field across a wire or wire loop(s). A voltage and/or current are produced in the wire cut by the changing magnetic field. Note: Only changing magnetic fields can induce a voltage; therefore this is only applicable to AC sources.

The classic model of magnetic coupling is a transformer: the AC source flows through the primary winding (coiled wire loops), creating a changing magnetic field in the "core" of the transformer. The changing magnetic flux in the core then passes across the secondary winding (coiled wire loops) and creates a voltage on, and usually current flow through, the secondary coil.

Vout =Vin*(# windings in secondary / # windings in primary)
Vout = Vin*(Lsec / Lpri)

Voltage on the secondary winding is based on the ratio of the inductance (L) on primary and secondary coils - usually the ratio of the turns. Voltage is fairly independent of the impedance of the secondary coils so lowering the secondary load impedance won't make much difference.

The transformer example uses an iron core because iron is an excellent magnetic conductor. High frequency transformers will use an "air core" for better linearity versus frequency. Notice in the transformer illustration that the magnetic flux flows perpendicular to the current flow in each wire of the transformer windings. Note: This will be key in the magnetic coupling test experiments. The magnetic field is perpendicular to the current flow in each turn, and the magnetic flux flows parallel to the wire-coil winding axis.

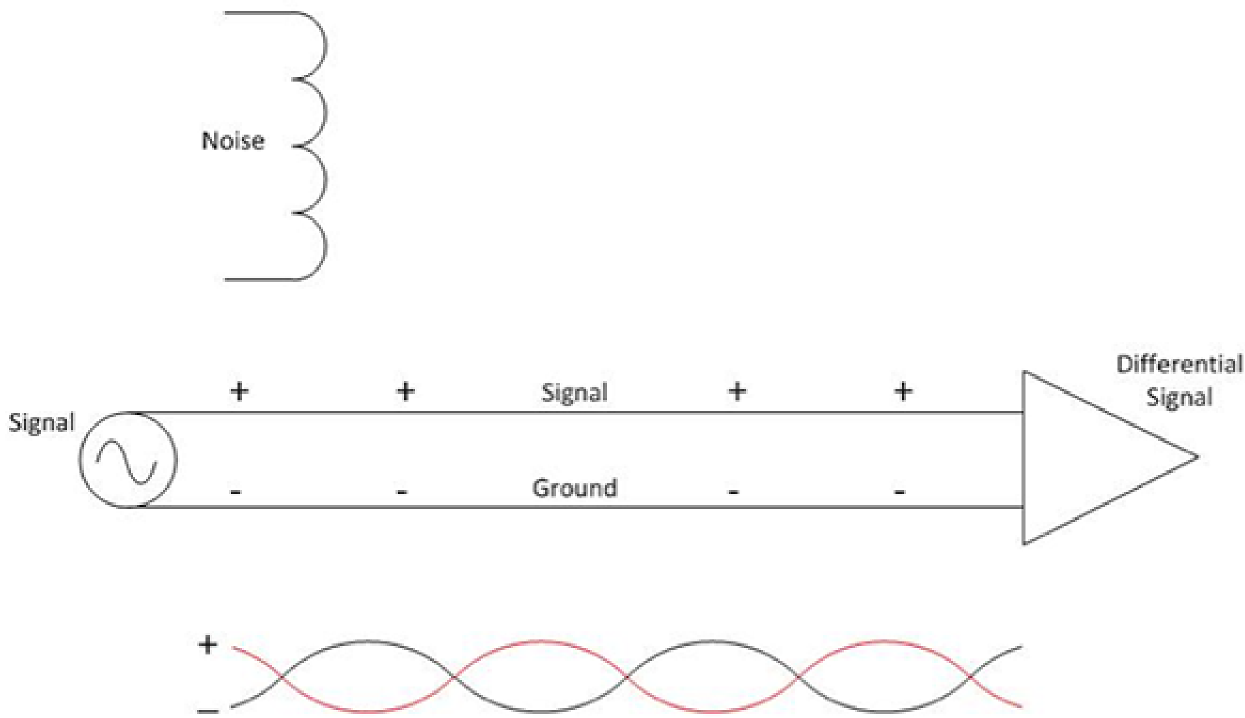
In Noise Debug 101 - Part 2, we saw how a grounded shield was very effective at stopping the electrostatic noise conduction. However, an electrostatic shield is very ineffective at preventing magnetic conduction because the thin metallic shield does very little to stop the magnetic flux.

Electrical Engineering Concepts

- The letter "L" is used as the symbol in equations in EE. Inductance is measured in "Henries." An inductor will impede a change in current flow.
- The formula for impedance of an inductor is: XL = 2π f L
- Inductance results in an AC signal impedance. An inductor will "impede" AC current signal flow, the same way that resistance "resists" DC current flow.
- An inductor is (almost) always made by a coil of wire, with 1 or more turns. However, even a straight wire has a very small bit of inductance.
- The inductance of a coil is related to the number of turns and the area of the coil. (The area of the coil will be key later in this part.)
- To induce a voltage signal in a coil, the magnetic field direction must be parallel with the axis of the coil (see above).
- The magnetic field generated is dependent on the inductance of a coil and the current flowing through the coil.
- Inductance = loop area * the number of turns
- More turns or larger area makes more inductance and thus more noise conduction.
- Magnetic fields cannot be shielded or destroyed, only diverted.

Lab Setup Example

In this example, the magnetic noise source may be a transformer in a power supply or the ballast in a florescent overhead light, denoted by the coil. Note: Most 12v DC LED lights have a high frequency circuit containing an inductor in the LED bulb to control LED current. Consider these as a possible noise source.



The “receiving inductor” is formed by the loop of: Signal source, Signal wire, Amplifier input, and the return Ground wire. The area of the loop is based on the length of the cable and the separation distance between the two wires. Twisting the wires will match and cancel the induced voltage signal at each twist.

Solution: To reduce magnetically conducted noise coupling,

- Turn the loop or turn transformer/power supply 90 degrees;
- Move away, move out of field – move tether extensions away from magnetic fields (older CRTs will have major magnetic fields);
- Reduce the loop area - twist exposed wires to keep them tight;
- Magnetic shielding – for high frequencies use Aluminum, Steel, or Mu Metal:
  - Aluminum (low cost) – about 24db (magnitude of signal reduced to 1/16 of the original) at F <10Khz
  - Steel (low cost) – about 20 db (reduced to 1/14 of the original) at F <10Khz, heavy
  - Mu Metal (very expensive) – about 10 db at higher frequencies; (Fe, Cr, Ni)

For situations where you have two or more long tether cables (ie., from a ceiling mounted commutator), you may see a reduction in noise by simply twisting the two tether extension cables together. By twisting the cables together, the amount of noise induced into both cables will either cancel, as above, or be closer to the same on the electrode and reference wires so the Common Mode Rejection of the Neuralynx Data Acquisition Systems will cancel the common mode noise.

Tests for Determining Magnetic Coupling

Note: Remember to use the audio monitoring of a channel in Neuralynx’s Cheetah software to listen for changes in the coupled noise during these tests.

- Use a headstage with a shorted input; this will avoid electrostatic coupling, and move to the suspected magnetic sources. When the source is found, rotate the headstage in all 3 axes to minimize and maximize the coupling. If the coupled noise changes when rotated 90 degrees, the coupling is probably magnetic.
- Twist or tie long cables together to minimize the “loop area” between the cables/wires. If this has an impact on shielded cables, the coupling is probably magnetic. Keep the twists in place and move the cables away from the source.

A good webpage on inductance can be found at:
www.allaboutcircuits.com/textbook/alternating-current/chpt-3/ac-inductor-circuits/