# 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:

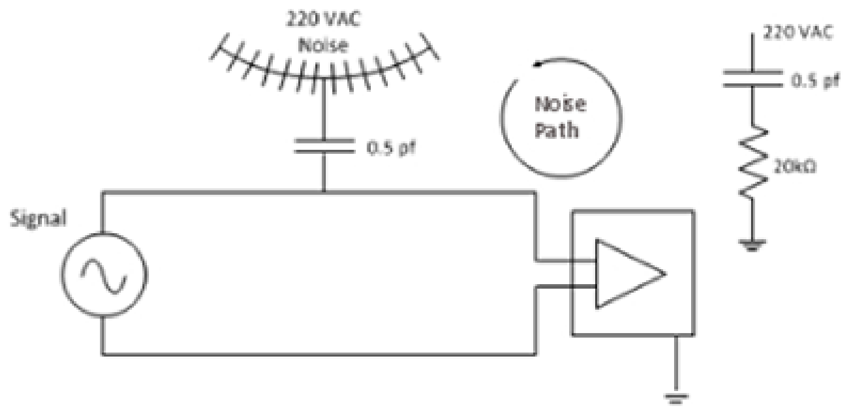
- Part 1 - Conducted Noise (common path voltage drop)
- Part 2 - Electrostatically Coupled (voltage coupled)
- Part 3 - Magnetically Coupled
- Part 4 - Radio Frequency Coupled
- Part 5 - Practical Noise Abatement

## Electrostatic Noise Conduction

Electrostatic Noise occurs when AC noise is coupled into the circuit via parasitic capacitance through the air/space. The noise source is any varying voltage and is independent of current flow. For example, an open energized power cord generates just as much noise as when it is powering a device. The amount of coupling is directly related to the frequency (higher frequencies will present more induced noise), distance (inversely), and voltage of the noise source (120/220 VAC). The most common sources are fluorescent lights, switching power supplies, or other common electronics in the lab.

The electronic model of the noise coupling consists of: 1) a parasitic capacitor (any two metallic areas separated by space) between the noise source to your circuit; and 2) the impedance of the circuit (amplifier input or electrode wire) shown as a resistor between your circuit conductor (the electrode, tether wire or PC Board trace) and ground. As mentioned before, current always flows in a loop because electrons must get back to the source. Therefore the conduction loop will usually be from the source, through the capacitance (air) and through your circuit (impedance), to ground and then back to the source (assuming the noise device is AC powered or connected to ground).

Schematic of Electrostatic-Noise Coupling




capacitor is usually about

impedance of the capacitor

Xc ~= 50 Giga-ohms (or more)

resulting noise into amp

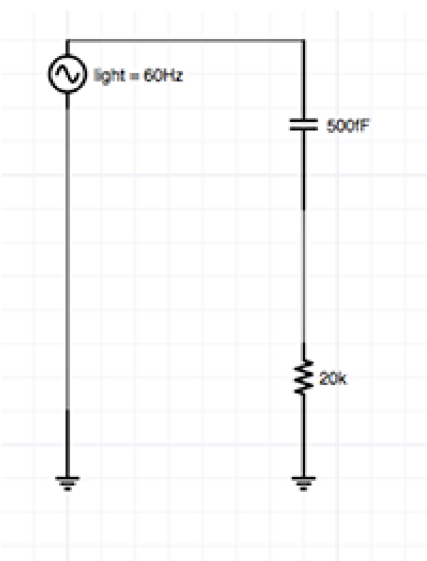
.5 picofarads

$Xc = 1/(2 \pi F C)$

50 Gohm

500 µv

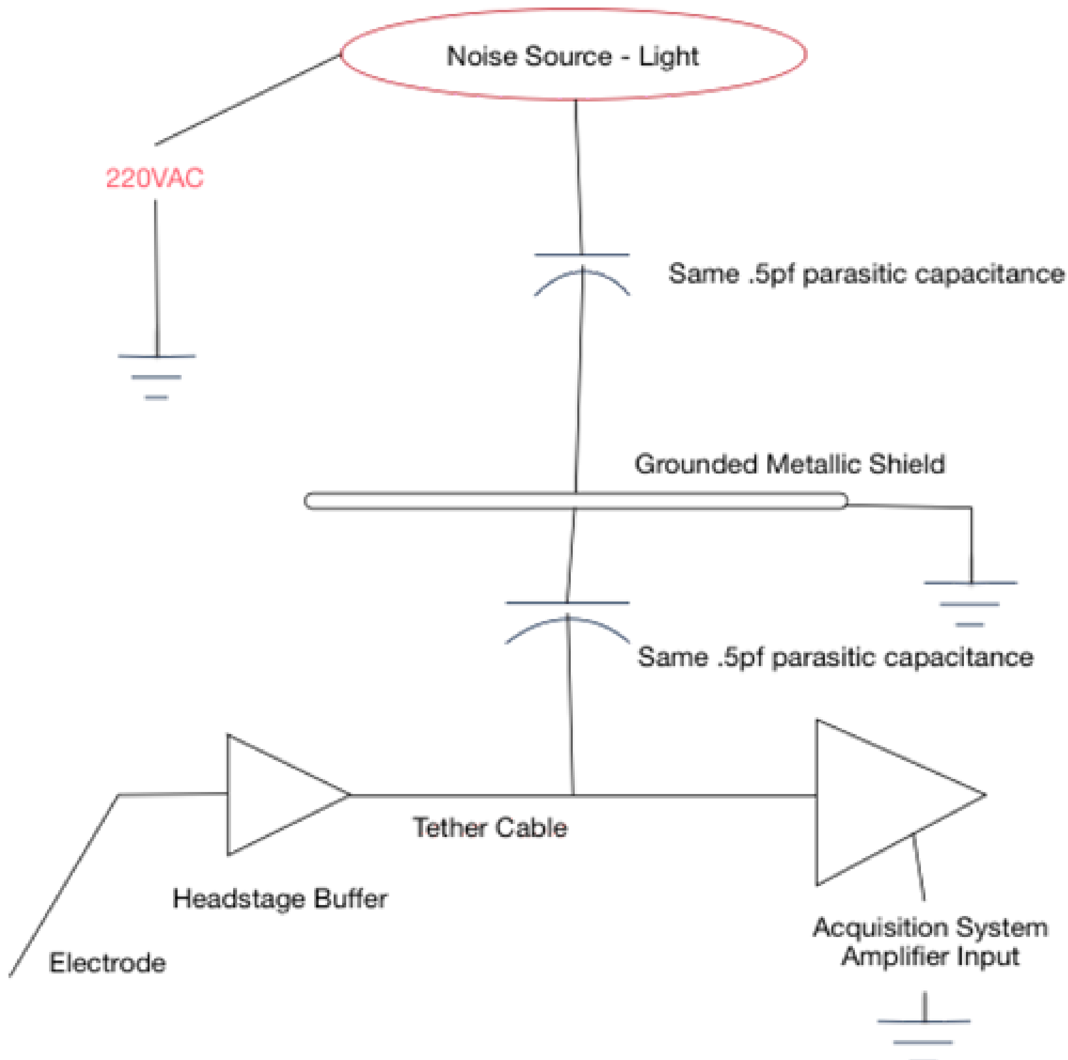
Electronic Model of Noise Conduction




In this noise example, the induced noise into the recording system will be about 500 microvolts but will vary based on distances, frequency, and impedances; it will still be in the range of 50 µv to 50 millivolts. Very consistent with what you will observe in the lab!

Electrostatic coupling is the one situation where the “aluminum foil” shields actually work!

Electronic Engineering Model of How Shielding Works




The shielding usually takes the form of an outer metal sheath around wires in the tether cable. This shield MUST be connected to ground to return the noise current back to the power source. The same amount of coupling capacitance is present between the noise source and the shield, but the shield is connected to ground. The voltage on the shield will still be about 500 µv, but is connected to ground for the return path for the current to return back to the AC power source.

Note: You now have a new parasitic capacitor between the shield and the tether wires, but because the shield only has 500 µv on it the amount of noise induced into the tether cable wires is very minimal – a few nanovolts – which results in a noise free signal measured by the recording system.

Practical Applications of Electrostatic Shielding As stated in Part 1, you first need to identify the noise source and then identify which of the four types of coupling is causing the noise to get into your recording system. Identifying the noise source is usually as simple as turning off lights or other devices to see if the noise immediately stops or changes. You may have multiple noise sources and each one must be dealt with separately.

Electrostatic noise coupling is usually the one encountered in electrophysiology recording because electrode impedances are so high (50Kohm to 2Mohm) and neural signal amplitudes are so small (20 µv to 5 mv). Usually the test for electrostatic coupling is the “aluminum foil shielding” test:

- put a grounded metallic surface between the noise source and your low level signals (electrodes, tethers, and microdrives)
- always connect the foil to ground (with a wire) to maximize the results of the test
- also place the foil around your subject

When you are performing this experiment, it is best to monitor your signals with an audio output. Your ears are the best “instrument” for detecting changes in a noise signal without having to continuously monitor a display or oscilloscope.

If you determine that electrostatic coupling is the cause of your contaminated signals, you may have to change cables to shielded cables, grounding the shields. If this is not possible, as in a Patch Clamp experiment, you may have to resort to a fully shielded Faraday Cage Enclosure, making sure to ground the cage.