Setup grounding

1. Introduction

This document shows how to properly build the ground connections for experimental setups involving delicate electrical measurements (e.g. neural recordings, EEG) which are subjected to electromagnetic noise.

2. Definitions

Let's start defining a terminology:

- "**setup**" = everything together strictly, and only strictly, related to the sensitive recordings to be protected from environmental electromagnetic noise (e.g. computer for the recording system and computer for the stimulus and recording equipment and stimulators, etc...). For instance from this point of view what is not part of a setup can be: a 3D printing facility used to print part of the setup, a soldering station for building the setup, a table together with all its related tools used to build up the setup, etc...

- "**equipment**" or "piece of equipment of the setup" = sub-parts of a setup which, as a whole, makes the setup (e.g. the computer for the recording system, the computer for the stimulus, the recording equipment, the stimulators, etc...). For instance from this point of view what is not a piece of equipment of the setup can be: the computer where the data collected from the setup are later analysed, the soldering iron used for building the setup, the fridge which stores biological samples related to the setup, etc...

- "**ground**" or "**grounding wire**" = the yellow/green electric wire carrying the ground signal.

- "**reference**" or "**referencing wire**" = the electric wire carrying the reference signal in an amplifier having a differential input.

- "**signal**" or "**signalling wire**" = the electric wire carrying the signal of interest to be protected from the environmental electromagnetic noise: it can be the input of a differential amplifier.

- "**clean ground**" = an electrical ground connection which is connected to a ground pole going directly into the earth soil by means of a short (as short as possible) electric path, also having good conductibility electrical properties and a low level of electrical noise.

- "**dirty ground**" = whatever is not a clean ground, e.g. a very long cable which is connected to an uncertain ground pole or a good ground pole on which a number of noisy devices are attached to, or a good ground pole with a few noisy devices attached to it but having the grounding wire passing too close a source of electrical noise (e.g. a potentially clean grounding wire tightly twisted to a known dirty grounding wire).

- "**grounding box**" = a plastic box having a proper clean ground connection. This box is compliant to the safety criteria and should be installed only by a certified electrician.

- "**grounding bar**" = a copper threaded bar connected to ground. It is present inside the grounding boxes and it can be attached to metal objects, like floating anti-vibration tables or racks. It serves as hub for the ground wires.

- "**electric island**" = an electric circuit which has a ground connection which is floating respect to another separate one.

- "**Faraday cage**" = a topologically closed cavity having very high electric conductivity. It shields very well delicate equipment from *radiated* electromagnetic noise.

- "**magnetic cage**" = a topologically closed cavity having very high magnetic permeability. It shields very well delicate equipment from *induced* electromagnetic noise.

3. Setup

Hereby a typical wired neural recording system setup is shown. It is composed of:

- an electrode implant, made of one ground electrode, one reference electrode and at least one, or many, signal electrodes.
- a headstage differential amplifier
- a data online acquisition, visualisation and storage system
- equipment related to the experiment (visual/tactile stimulators, motorised micro manipulators, etc...whatever is necessary to run the experimental task)
- the experimental subject (e.g. rat)

These things, from the point of view of the ground connections, should be connected as follows:

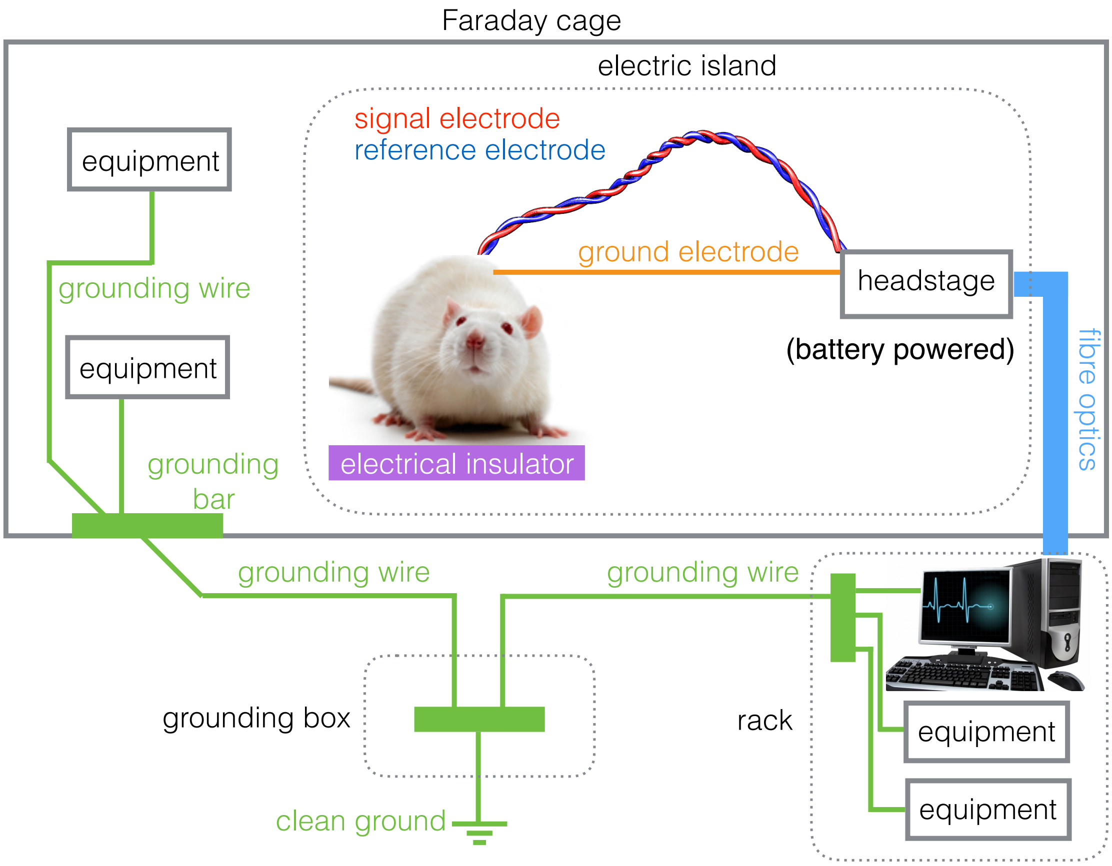

Fig. 1: A setup example.

Notice the "star shaped" grounding circuit topology:

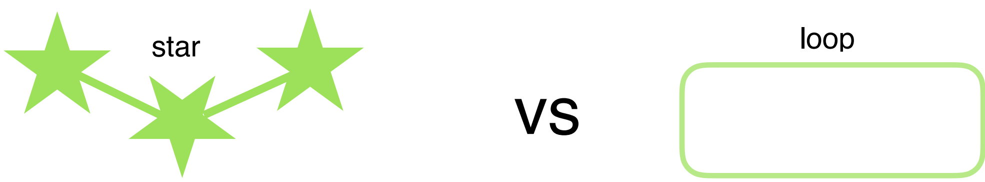

Fig. 2: "Star" vs "loop" circuits.

This breaks the so called "ground loops", hence reducing the possibility of receiving electromagnetic noise by induction.

4. Grounding circuit

Good grounding circuits should avoid "ground loops" as much as possible. Sometimes avoiding loops is not possible: still, if they are present, it is a good idea to keep them as small as possible and as few as possible.

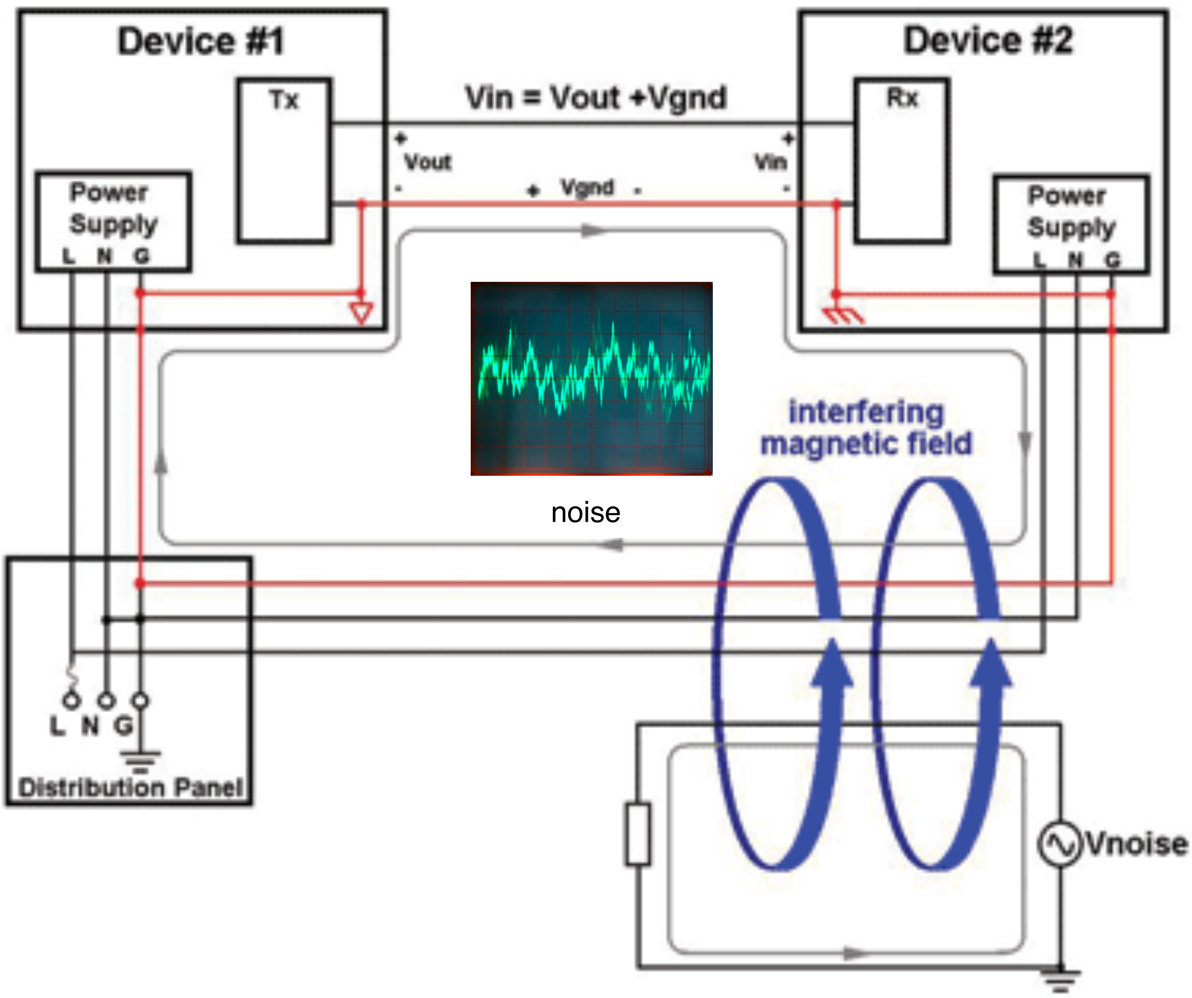

Fig. 4: Ground loop, detailed circuit.

In a few words, ground loops are bad because they can capture electromagnetic noise by induction: the "star" circuit topology goes in favour of reducing the noise because it breaks the loop, therefore no electromagnetic induction is possible if the electrical path is not topologically closed. In Fig.4 notice the "L" = "Line" and "N" = "Neutral" wires, which carry the AC power coming from the mains, in this case (and usually) do not make a closed loop. In this example the loop if formed mainly because the "Device #1" wants to send a signal to the "Device #2" and by doing so it have to share the same common ground. In Fig.3 a similar situation has been avoided by means of a fibre optics link between the headstage amplifier inside the Faraday cage and the acquisition system mounted on the external rack. This makes the subject being an "electric island".

When the noise in a setup comes in form of induction more than in form or radiation a "magnetic cage" is sometime more useful than an Faraday cage. They can be both used simultaneously if necessary (e.g. in a EEG setup).

5. Implementation of a good grounding system.

Due to the reasons discussed in this essay, it is recommended to organise the setup as follows:

- Divide the setup in confined sub-units like a Faraday cage, a table or a rack.
- Recognise each setup sub-unit as a "standalone world" having its own "ground", implemented as a "grounding bar" to which every "grounding wire" coming from that world would electrically converge in a star-shaped grounding circuit. In case of a Faraday cage or a metallic rack (which is similar, at least as a concept, to a Faraday cage) the grounding bars should also be in electrical contact with the metal of the enclosure.
- Connect together each of these "standalone worlds" through a single grounding wire each, again in a star-shaped grounding circuit, to a single "grounding box".
- Make sure that extra intrinsic grounding connection which might be present in all the equipment of interest (e.g. there usually is a ground wire inside each power cord that connects the equipment to the power main outlet) in the setup shares the same common clean ground.
- Avoid connecting "noisy" devices to a power line having a clean ground: this can easily spoil the good quality of it. Such devices should be instead power up by means of a different set of outlets where a dedicated "dirty ground" is present and separate from the "clean ground" in both electrical and physical (spatial displacement) sense.

6. Pratical considerations

The grounding wires should be supplied and mounted by a certified electrician (or equivalent laboratory technician). The user of the setup should be aware of a few important things:

- ***Ground connections are there not only for reducing the noise but also for safety reasons: in case of any electric dispersion they can save a person's life. Do not modify them yourself.***

- ***Any modification of the grounding and power scheme in the laboratory might create negative side effects on the modified setup as well as on other setups, even if they are far.***

- ***Temporary and "pirate" connections are easily forgotten and because of this they have the tendency of being secretly accumulated as time goes by. This usually leads to uncontrolled situations which later can be very hard (if not also practically impossible) to fix.***