Audio applications and noise on the mains

Many audio enthusiasts who own a high-end audio system are constantly looking for ways to improve the sound quality. This search includes, for example, experimenting with other cables, feet or audio components. Insufficient attention is often paid to the influence of pollution on the mains and the earth, while there is a lot to be gained here. Noise on the mains and ground almost never manifests itself in obvious ways, such as hum or other audible noise, but rather hides itself in the background. This results for example in haze, too much sharpness, limitation of dynamics, loss of musical details or reduction of spatiality. Usually it is a combination of these unwanted effects.

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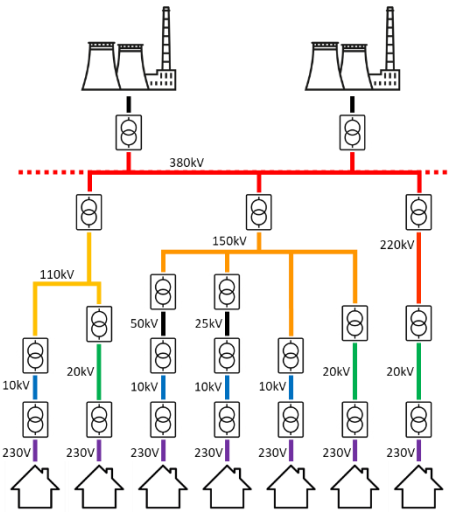
It is a well-known statement that “an audio system is as good as its power supply”. This is because the power supply is in the loop of the electrical parts that generate and amplify the audio. But you can also state that an audio system is as good as the quality of the mains power, because the electricity grid is part of the power supply. When appliances that generate noise on the mains are powered on, the sound quality decreases. Because we cannot control the quality of the power received from the electricity grid, it makes sense to see what can be done to locally improve the power quality for your audio system. Installing a good line conditioner and the use of a dedicated System Earth will almost always breathe new life into an audio system.

Power grid architecture

In western Europe, most of the electrical energy is produced in power plants. This energy is first transformed to a high voltage to reduce the loss of power during long distance transport. A common voltage is 380kVAC. Using transformers, this voltage is gradually reduced to the 230VAC that is provided through the wall outlets.

The 230VAC wall socket contains three conductors: Live, Neutral and Earth. The Live and Neutral conductor provide the necessary energy to the connected appliance. The Earth conductor is used for human safety in fault condition, called Safety Ground, and as protection of the connected appliances, called Protective Earth. But this earth conductor is also used as reference in your audio system.



► *Indicative representation of the grid*

The Protective Earth is implemented in several ways. There are implementations in which the Protective Earth is provided by the energy supplier as a separate wire, and implementations in which the earthing is realised with a locally installed ground rod or connection to the water supply network. In all cases, the Protective Earth is connected to the Neutral at some point. The location where this connection is made, varies from country to country and the age of the fuse box, as regulations changes over the years. In general this connection is made at the transformer substation that converts the voltage to the 230VAC for distribution to end users, or locally in the fuse box.

Noise on the Power grid

Most electrical appliances generate noise due to the way the electrical energy is used, for instance:

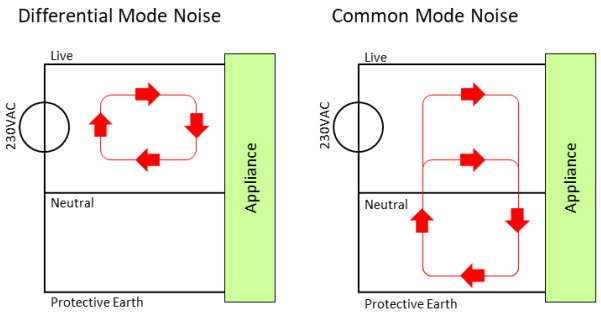
- Constant changing load, like dishwashers, tumble dryers and washing machines.
- RF noise by switched power supplies, like TV's, cell phone chargers and computers.
- Devices that use only a part of the sine-wave, like dimmers and conventional power supplies.
- Devices with motors that use brushes.
- Switched power supplies from solar panels that feed back into the grid.

Because the energy required to create the sound in the audio system is taken from the mains, the power grid is in fact part of the audio system. As a result, noise on the mains will have a negative effect on the sound quality. A part of the noise on the Live and Neutral is filtered by the power supply in the audio appliances through rectifiers and capacitors, but enough remains to affect the sound quality.

What is often forgotten is that there is also Noise on the Protective Earth. As the Protective Earth is commonly used as ground reference in an audio system, the noise coming from the Protective Earth has a serious impact on the sound quality.

All types of mains disturbances can be reduced to two types of noise:

- Noise across Live and Neutral, with equal amplitude but in opposite phase. So relative to the Protective Earth they cancel themselves out. This is called Differential Mode Noise.
- Noise that exists on both the Live and Neutral, equal in phase and amplitude, relative to the Protective Earth. This is Common Mode Noise.

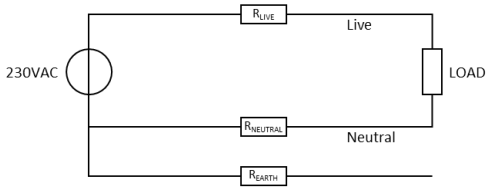


► *Differential and Common Mode Noise on the mains*

Differential Mode Noise on Live and Neutral

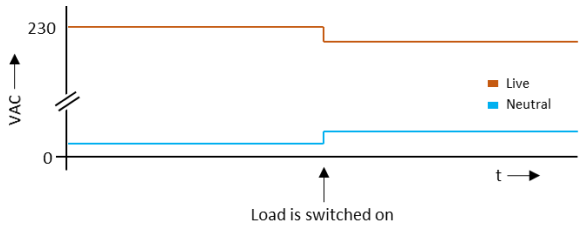
To understand the source of the Differential Mode Noise, we first have a look at a simplified model of the mains, in which only the ohmic resistance is considered for the load and the wire impedances.

As the wires used to connect the wall outlet are long, the resistance of these wires result in a voltage drop when energy is used.



► *Simplified model of the last section of the mains*

The magnitude of this voltage drop depends on the current through the wire and its length, and can be several volts. As a result, at the Load, a voltage drop is created between the Live and the Protective Earth, and an equal voltage is created between the Neutral and the Protective Earth (presuming R_{LIVE} is equal to $R_{NEUTRAL}$). This is illustrated in the image below. The sum of the voltage on Live and Neutral is constant relative to the Protective Earth.



► *Differential Mode distortion by turning on a load*

In reality, we are not only dealing with the ohmic resistance, but the inductance and capacitance of the conductors also play an important role in the magnitude and shape of the noise, especially if these fluctuations occur at high frequencies.

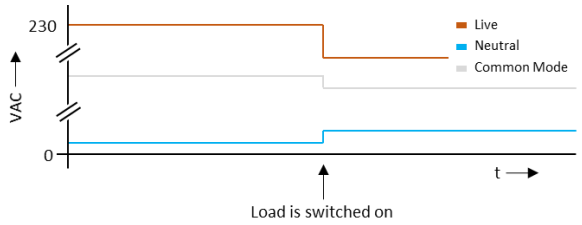
Common Mode Noise on Live and Neutral

In the event of fluctuating currents as described in the simplified model above, the amplitude of the fluctuations on Live and Neutral are usually not equal. This has several causes, including:

- The location where the Neutral is connected to the Protective Earth.
- Difference in the length of the Live and Neutral wire, resulting in a difference in resistance, inductance or capacitive coupling of the Live and Neutral wire.

- The impedance of the wires that feed the last transformer substation from where the 230VAC is supplied.

These all result in a difference in voltage fluctuations on Live and Neutral. Usually the fluctuations on the Live are bigger.



► *Common Mode distortion by turning on a load*

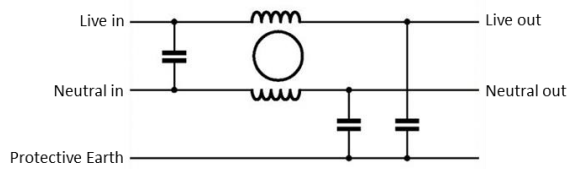
The difference in voltage fluctuations is the Common Mode Noise component of the noise signal. This is noise that exists on both the Live and Neutral -equal in phase and amplitude- relative to Protective Earth. Thus, a fluctuating load results in both Differential Mode Noise and Common Mode Noise.

This example only looks at the Noise from fluctuating loads. However, both Common Mode and Differential Mode Noise can have also other causes, like radiated signals coupled into power lines or noise generated by appliances.

Noise on the Protective Earth

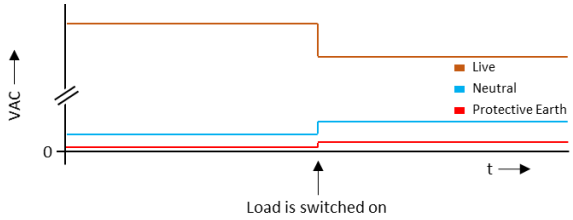
The above described Common Mode Noise is noise on Live and Neutral relative to the Protective Earth, but Common Mode Noise can also arise from voltage fluctuations on the Protective Earth.

The noise on the Protective Earth has different causes, but mains filters probably have the biggest contribution. Mains filters are placed at the inlet of noise generating devices, to reduce the amount of noise fed back to the mains. These filters consist of inductors and capacitors, in which the Protective Earth is used to drain a part of the noise.



► *Typical mains filter*

The energy drained by the Protective Earth via the two capacitors, result in a current through the Protective Earth wiring and a voltage over it. This means that the Protective Earth at the wall socket also contains noise, which results in Common Mode Noise.

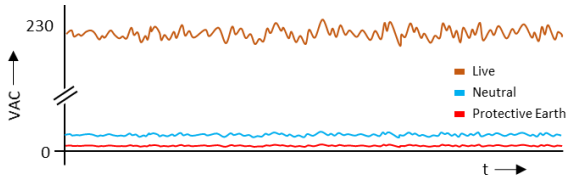


► *Common Mode distortion via Protective Earth*

There are also other causes of noise on the Protective Earth, like ground loops and radiated signals coupled into Protective Earth conductors.

Composition of noise on the mains

Electrical energy from the grid is used by millions of users. This means that there are even more electrical appliances connected. This entire electrical system results in a constant changing load and disturbances generated from appliances, which is perceived in the form of noise modulated on the Live, Neutral and Protective Earth.



► *Indicative composition of noise on the mains*

It is the Common Mode noise that has by far the biggest impact on the sound quality. That's because it is this noise that causes electrical current in the Protective Earth, resulting in a disruption of the audio reference.

The noise on the mains is broadband, from DC to radio frequencies greater than 100MHz. The exact composition of the noise spectrum depends on the place and time and is usually unpredictable. The only thing that can be noticed is that there is less activity on the mains at night. This is the time of the day when the amount of noise will usually be lower and therefor the best time to listen to music.