Haandrikman
Audio Systems

Audio applications and noise on the mains

Many high-end audio enthusiasts are in a constant quest to refine their sound quality. They experiment with different cables, feet, or audio components, but often overlook the significant impact of pollution on the mains and the earth. This type of noise rarely presents itself through obvious symptoms like hum or other audible disturbances. Instead, it subtly hides in the background, leading to issues such as haze, excessive sharpness, reduced dynamics, loss of musical details, or diminished spatiality. Typically, it's a combination of these undesirable effects that degrade the overall audio experience.

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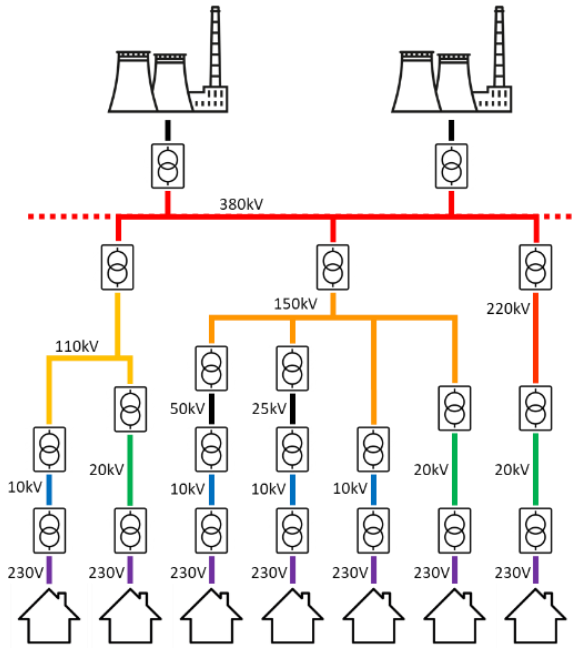
It's a well-known statement that “an audio system is only as good as its power supply.” This is because the power supply is integral to the electrical components that generate and amplify the audio. However, one could also argue that an audio system is only as good as the quality of the mains power, as the electricity grid forms part of the power supply. When devices that introduce noise to the mains are powered on, sound quality diminishes. Since we can't control the quality of electricity from the grid, it's sensible to see what can be done locally to improve power quality for your audio system. Installing a quality line conditioner and using a dedicated system earth can almost always breathe new life into an audio setup.

Power grid architecture

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

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



► *Indicative representation of the grid*

Protective Earth is implemented in various ways. Some implementations provide the Protective Earth as a separate wire from the energy supplier, while others realise the earthing with a locally installed ground rod or a connection to the water supply network. In all cases, the Protective Earth is connected to the Neutral at some point. The location of this connection varies by country and depends on the age of the fuse box, as regulations have changed over the years. Generally, this connection is made at the transformer substation that converts the voltage to 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 electrical energy is used, for instance:

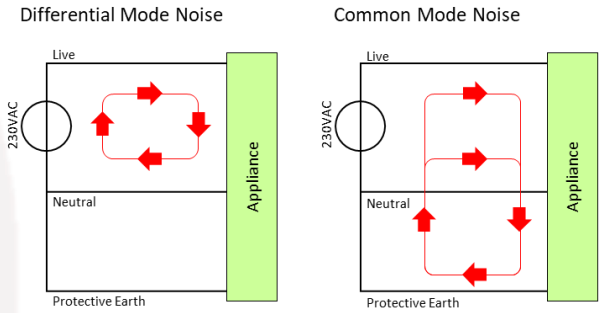
- Constantly changing load, like dishwashers, tumble dryers and washing machines.
- RF noise from switched power supplies, like TVs, mobile phone chargers and computers.
- Devices that use only a part of the sine wave, like dimmers and conventional power supplies.
- Devices with motors that use brushes.
- Inverters for solar panels that feed back into the grid.

Since the energy required to create the sound in the audio system is taken from the mains, the power grid is effectively part of the audio system. Consequently, noise on the mains will negatively affect sound quality. While some of the noise on the Live and Neutral is filtered by the power supply in the audio equipment through rectifiers and capacitors, enough remains to degrade sound quality.

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

In general, all types of mains disturbances can be categorised into two types of noise:

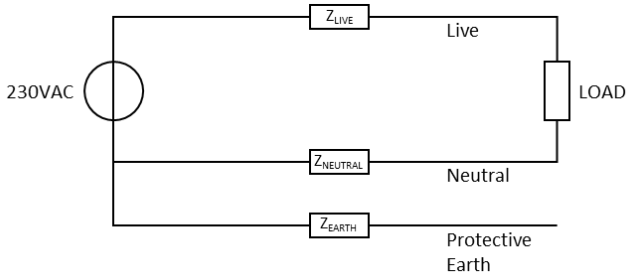
- Noise across Live and Neutral, with equal amplitude but in opposite phase. Relative to the Protective Earth, they cancel each other out. This is known as Differential Mode Noise.
- Noise that exists on both the Live and Neutral, equal in phase and amplitude, relative to the Protective Earth. This is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



Differential and Common Mode Noise on the mains

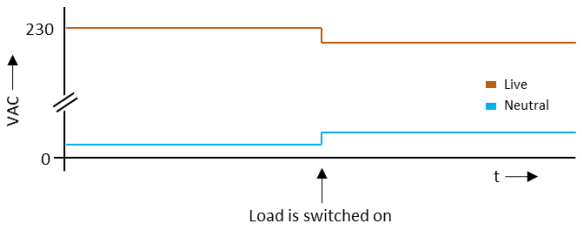
Differential Mode Noise on Live and Neutral

To understand the source of Differential Mode Noise, we first look at a simplified model of the mains.



Simplified model of the last section of the mains

The wires used to connect the wall outlet are long, and each wire has its own frequency-dependent impedance. Due to the impedance of the wires, each wire will cause a voltage drop when a load is applied. The magnitude of this voltage drop can be several volts. This depends on the current through the wire, the frequency-dependent impedance, and its length. As a result, at the load, a voltage drop is created between the Live and the Protective Earth, and also between the Neutral and the Protective Earth. This is illustrated in the image below.



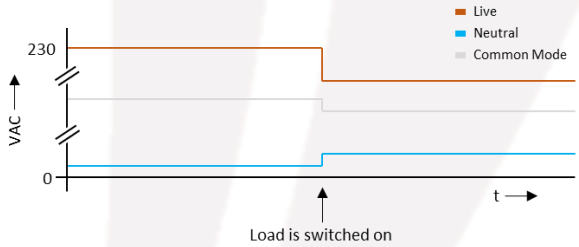
Differential Mode distortion

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:

- Not all power is returned through the Neutral conductor; a part is returned via the Earth conductor.
- Differences in resistance, inductance, or capacitive coupling of the Earth, Live, and Neutral wires.
- Electromagnetic coupling in cables and wires, for instance, due to radio waves or electromagnetic fields.

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



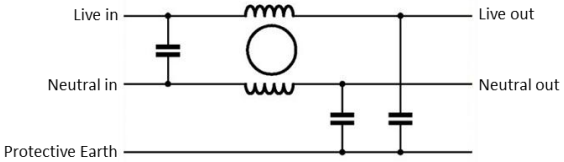
Common Mode distortion

The difference in voltage fluctuations -the grey line in this graph- 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 focuses solely on the noise from fluctuating loads. However, both Common Mode and Differential Mode Noise can also arise from other sources, such as radiated signals coupling into power lines or noise generated by appliances.

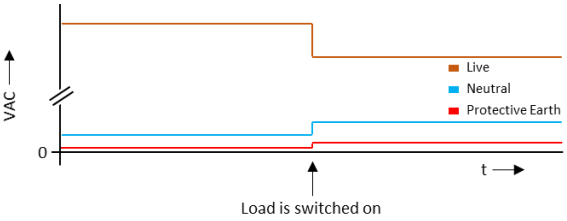
Noise on the Protective Earth

The Common Mode Noise described above is noise on Live and Neutral relative to the Protective Earth, but it can also arise from voltage fluctuations on the Protective Earth. The noise on the Protective Earth has various causes, with mains filters usually being the biggest local contributors. 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, using the Protective Earth to drain a part of the noise.



Typical mains filter

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

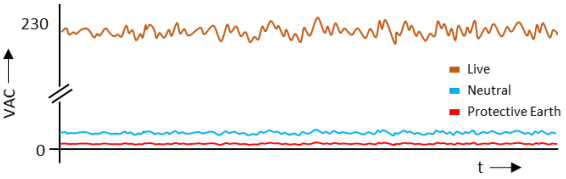


Common Mode distortion via Protective Earth

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

Composition of noise on the mains

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



Indicative composition of noise on the mains

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

The noise on the mains is broadband, ranging from DC to radio frequencies greater than 100MHz. The exact composition of the noise spectrum depends on the location and time, and is usually unpredictable. One noticeable pattern is that there is less activity on the mains at night. This is typically when the amount of noise is lower, making it the best time to listen to music.

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