DC Power Supply Noise Reduction and Measurement

By Ralf Ohmberger, Applications Engineer at MPS

Abstract

DC switching power can generate audible noise, which is often heard as a slight whistle. Where does audible noise come from, and how can it be reduced or eliminated? This article will describe simple ways to prevent noise while measuring and designing an application. Read on to find common weak points in existing or planned PCB designs for DC power supply circuits.

Introduction

It is a common belief that multi-layer ceramic capacitors (MLCCs) or DC power supply circuits cause audible noise, but that's not true. The noise is generated by the printed circuit board, not by the components.

Figure 1 shows three typical evaluation boards. The noise of these components, as well as the influence of the circuit board size and its mounting, are examined step-by-step throughout this article.

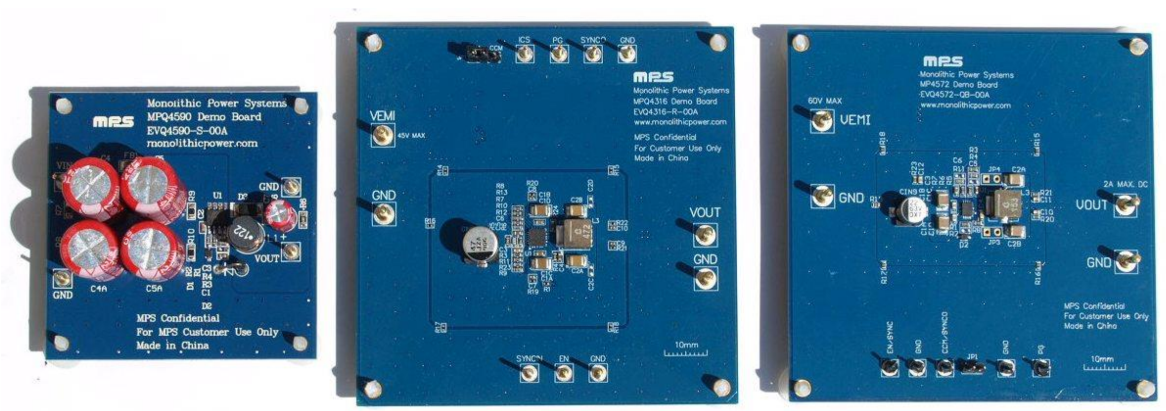

Figure 1: Evaluation Boards (1)

Note:

1) From left to right: The MPQ4590, a 640V, non-isolated regulator with up to a 400mA output current from MPS; the MPQ4316, a 45V, 6A, low-I_Q, synchronous step-down converter with frequency spread spectrum from MPS; the MPQ4572, a 60V, 2A, high-efficiency, fully integrated, synchronous buck converter from MPS.

Vibration Source

When the voltage on an MLCC ceramic capacitor changes due to the piezoelectric effect, the geometry of that capacitor changes, which results in a vibration (see Figure 2).

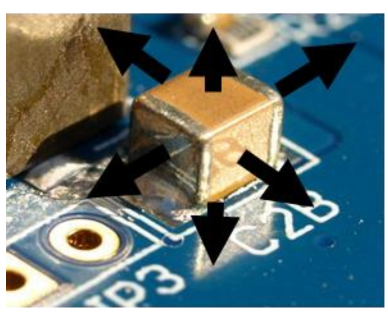

Figure 2: MLCC Vibrations

How Does Noise Arise on the PCB, and Which Components of a DC Power Supply Circuit Are Responsible?

A voltage change occurs in a ceramic capacitor (MLCC) generates a vibration stimulus. Vibrations are easily audible in the speech-sensitive frequency range (0.1kHz to 7kHz). The vibration is transferred to the PCB via the solder joints. The PCB then emits an audible noise comparable to a loudspeaker membrane.

Figure 3 shows the typical components in a DC power supply circuit. MLCCs and the dimensions of the PCB are key to audible noise, as other components make no noise.

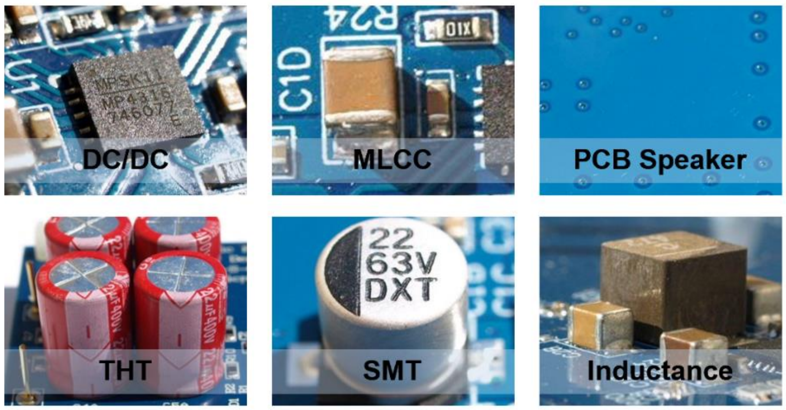

Figure 3: MLCC Is the Vibration Stimulus, PCB the Noise Source

Not all MLCCs behave in the same way. Only high-capacity Class II and III MLCCs have the piezoelectric effect. Other types of capacitors, molded inductors, resistors, and ICs do not show any change in geometry under a load. This means other components are insignificant sources of noise (see Table 1).

Table 1: Component Classification in Audible and Inaudible Systems

	MLCC Class I NPO, COG	MLCC Class II, III X7R, X5R, Y, Z	MLCC Class II, III Interposer Type, Metal Strip	Electrolytic Tantalum Organic Capacitors	Switching Inductance (Molded)	Ferrite Beads, Resistors, DC/DC Converters
Stimulus	No	Yes	Damped	No	No	No

DC Power Supply in FCCM or AAM

A DC power supply circuit operating in forced continuous conduction mode (FCCM) only produce audible noise within the speech-sensitive audio frequency range (e.g. GSM pulses or other periodic loads). A high DC switching power frequency is not audible.

When a DC power supply circuit operates in advanced asynchronous mode (AAM), light-load mode switching frequencies can be in the lower kHz range below 20kHz. AAM switching frequencies are not fixed frequencies; they are random, which reduces audibility. AAM is only active under light-load currents, where there is generally no strong stimulus, and therefore seldom noise.

Comparing Three Mechanical Systems

Audible noise on a PCB is created the same way that sound is generated on a stringed instrument (see Figure 4).

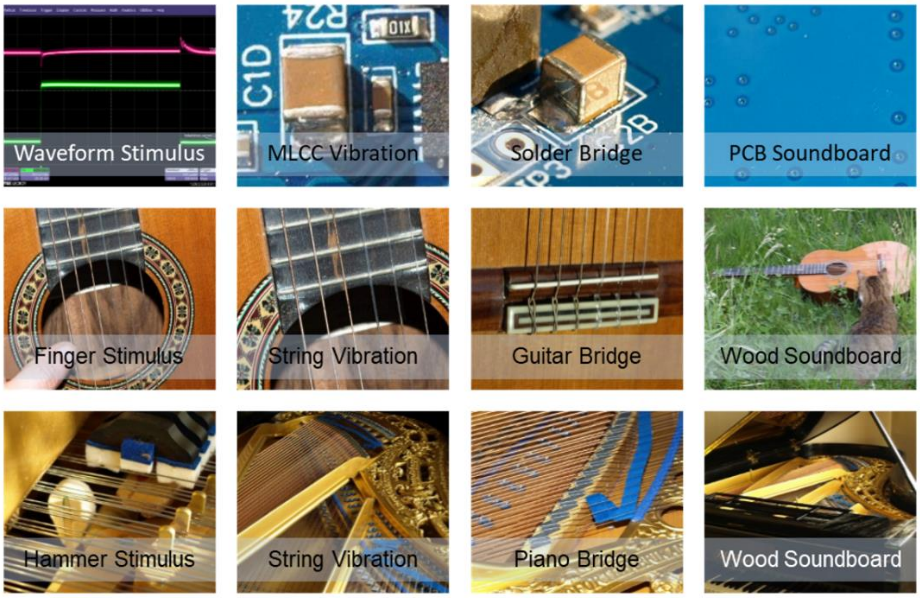

Figure 4: PCB Sounds and Music

This theory is described in further detail below:

1. Stimulus: The system receives an input signal, called the stimulus. The human ear is the most sensitive between 2kHz and 5kHz, which is in the same range as the resonance frequency of many PCBs. The stimulus waveform is like a finger strumming a guitar or a hammer hitting a chord. It acts as a Dirac impulse, and many components contribute to the frequency, such as PCB resonance, the stimulus hitting the string, and the PCB response with audible fundamental frequency and overtones. The loudest noise occurs when an MLCC vibrates at a frequency that is equal to the PCB resonance frequency.
2. Vibration: Vibrations transfer force into movement. An MLCC vibrating in free air is not audible, as the vibrating surface is too small. This motion is similar to how a vibrating instrument or string is hard to hear without amplification.
3. Bridge: Vibrations are transmitted into the soundboard. The bridge (solder junction) transmits vibrations. MLCCs with metal solder strips or an interposer substrate damp the transferred vibration energy.
4. Soundboard: The soundboard transfers the vibration into audible noise. The PCB acts as the soundboard, comparable to a loudspeaker membrane.

Measuring PCB Noise with a Microphone

Acoustic noise and the resonance frequency of a DC power supply circuit and PCB mount can be measured with a microphone and a small object that provides a Dirac impulse stimulus. A good choice is a condenser microphone, which is less sensitive against the magnetic field of the MLCC than a dynamic microphone.

A stick made of hard plastic or a plastic tweezer can be used as a simple mechanic stethoscope to make an audible noise easier to hear (see Figure 5). Metallic objects make a louder noise, which can help search for points with a higher vibration amplitude.

Figure 5: Set-Up to Measure Audible Noise

Comparison between a powered and unpowered microphone measurement shows that the PCB resonance frequency is exactly the same (see Figure 6).

Powered condition: The PCB is excited by an electrical signal. A 250Hz load step causes the MLCC to vibrate, which excites the PCB at the 3900Hz resonance frequency.

Unpowered condition: The PCB is excited by a mechanical shock, and a short push with the plastic stick causes the PCB to vibrate mechanically at the 3900Hz resonance frequency.

The type of excitation, whether mechanical or electrical, has no influence on the resonance frequency of the PCB. The mechanical shock test can show the acoustic behavior of a test PCB, which behaves similarly to the later series PCB, as long as the dimensions and attachment points are comparable.

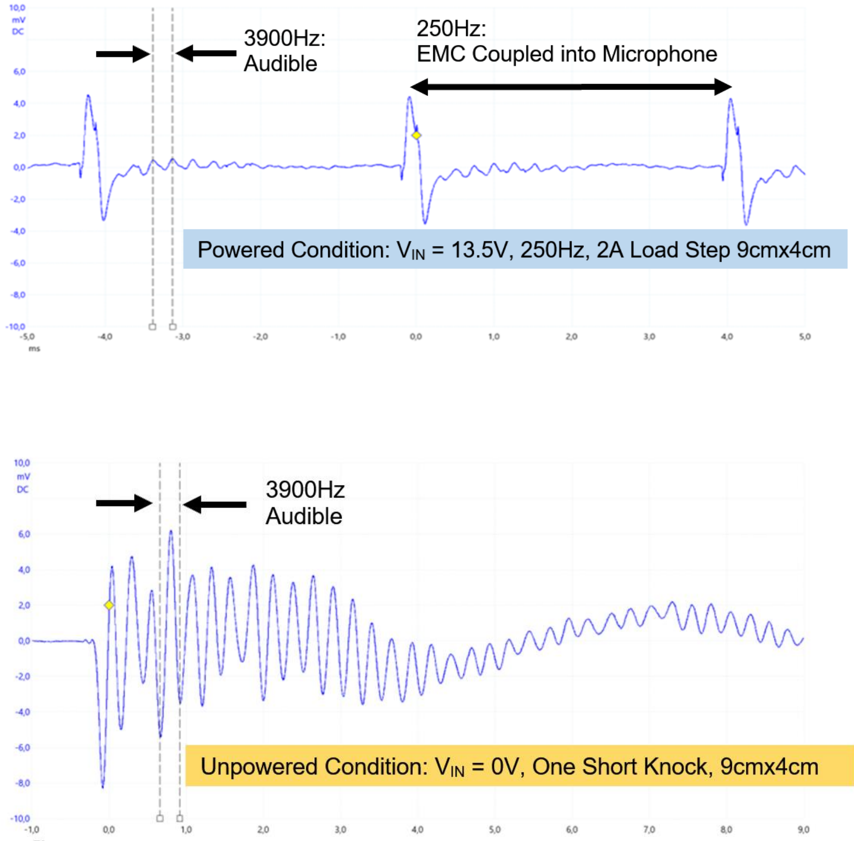

Figure 6: Measuring a 9cmx4cm, Full, Assembled Series SMT PCB using MPS's MPQ4572

Measuring PCB Noise with a Turntable and Microphone

If a piezoelectric accelerometer is not available, a turntable is a simple alternative that can measure the exact horizontal vibration on the diamond (see Figure 7). If a moving magnet or moving coil cartridge are the only unpowered measurements, the magnetic field of the capacitor current disturbs the signal. For a powered measurement, a crystal cartridge is a better choice to measure vibrations. While the microphone measures the integral, the cartridge or piezoelectric accelerometer measures a defined point.

Figure 7: Turntable Set-Up to Measure Horizontal Vibration

Microphones show a second hammer touch and the mechanic bounce during hammer impact. The large cartridge amplitude shows the horizontal movement of the PCB and the cartridge with the tonearm. The PCB here is supported on two sides, and is free above the rubber mate of the turntable.

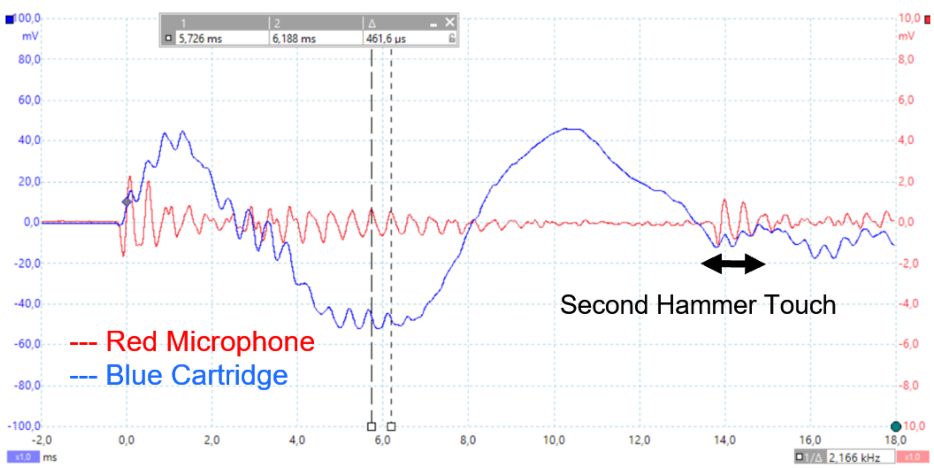

Figure 8: Set-Up to Measure Between Audible Noise and Single-Point Vibration

Table 2 lists different resonance frequencies under different conditions.

Table 2: Resonance Frequency vs. PCB Size

PCB Size	Condition	Resonance Frequency
4cmx4.5cm	Pressed with force lying on turntable rubber mate	5690Hz
4cmx4.5cm	Lying on turntable rubber mate	5058Hz
4cmx4.5cm	Two sides supported	4552Hz
9cmx9cm	Lying on turntable rubber mate	3742Hz
6cmx6cm	EVQ4590 free lying	3506Hz
9cmx9cm	EVQ4316 free lying	2395Hz
9cmx9cm	Two sides supported	2166Hz

During the practical design, a mechanical model of a PCB in a preliminary design status can be used for the first measurements. Mount the PCB in the housing before measuring the resonance frequency, and measure both in combination.

Superimpose Vibration Frequencies and PCB Vibration Transfer Functionality

Calculate the fast Fourier transformation (FFT) of the load currents (see Figure 9), and compare these values with the resonance frequency from a PCB model. Check whether a calculated frequency reaches the PCB resonance frequency.

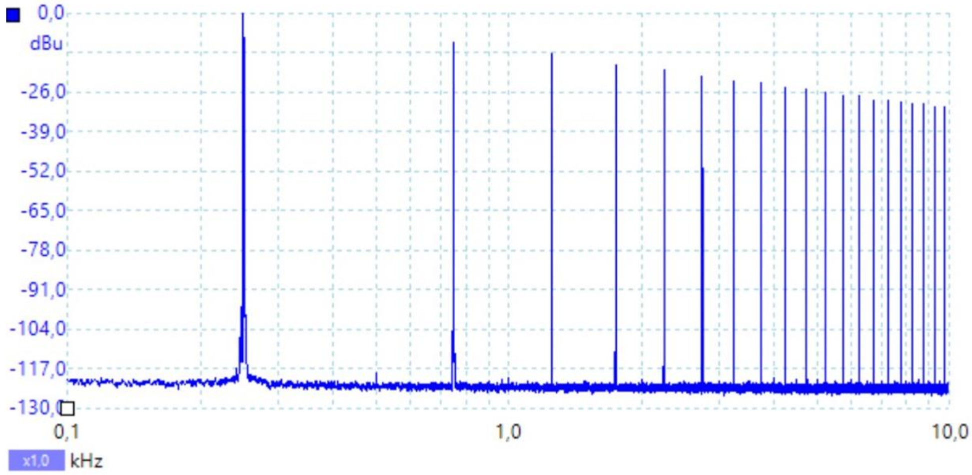

Figure 9: Fast Fourier Transformation (FFT) of a 250Hz Square Wave

A PCB has a vibration transfer function, which approximately corresponds to a mechanical second-order resonance system. It consists of a mass and spring constant, defined by PCB size and stiffness (see Figure 10).

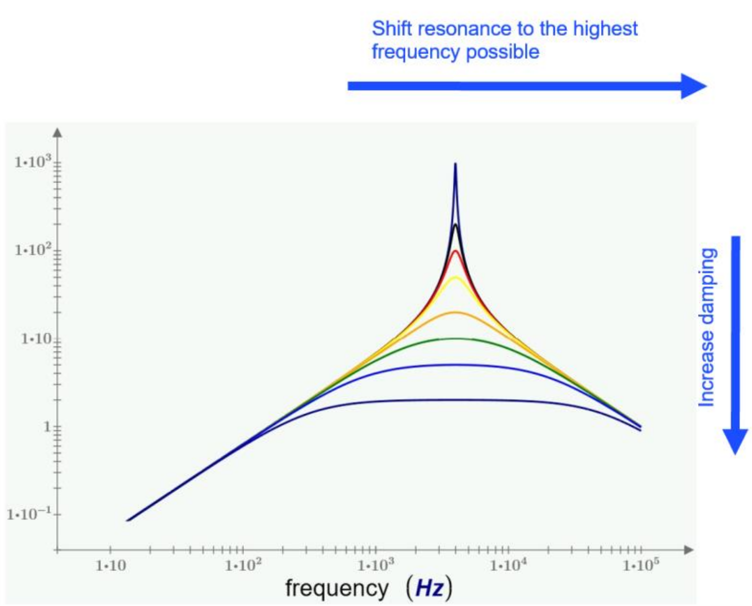

Figure 10: Simplified PCB Vibration Transfer Function

Superimpose the FFT with the PCB vibration transfer function, then check for overlapping frequencies with the PCB resonance. Consider the mechanical design and ensure that large vibration amplitudes cannot reach the area of the resonance frequency.

How to Reduce Noise for a DC Power Supply Circuit

Around the area of the PCB resonance frequency, vibrations are clearly audible. Avoid overlapping vibration frequencies and resonance frequency.

For most PCBs, it is not possible to change the electrical excitation, but the PCB can be changed in the following ways to avoid acoustic noise:

1. Shift the resonance frequency of the PCB as high as possible, above the vibration frequencies. More attachment points increases PCB resonance frequency.
2. Increase PCB damping and use mounting points with soft damping materials (e.g. plastic, rubber).
3. A smaller PCB size increases the resonance frequency.
4. A larger area in contact with damping material increases damping and reduces audible noise.

Conclusion

A change in the voltage on an MLCC ceramic capacitor causes a change in its geometry due to the piezoelectric effect, resulting in a mechanical movement. This vibration generated in the MLCC is transferred to the PCB via the solder joints, which can amplify it audibly, similar to a speaker membrane. The frequency components of the vibration, the dimensions of the PCB, its mass, spring constants, and the type of installation determine whether an audible noise is generated.

When developing a DC PCB mount, take care to attach the circuit board to many distributed mounting points to increase the resonance frequency. Fastening with vibration-damping materials dampens the quality of the resonance frequency. Avoid vibration frequencies that can excite the PCB's resonance frequency. Hardware developers should consider whether audible noise on a circuit board is distracting, such as on a phone or monitor in a quiet environment.

The frequency spectrum to be expected in the MLCC caused by the electrical load profile must be determined. The resonance behavior of the planned, assembled PCB must be estimated. With this knowledge, the mechanics of the DC power supply circuit and PCB design can be optimized in advance.

The methods described in this article can help engineers estimate whether acoustic problems are likely, and save multiple developments of PCBs.