

Reduce the Acoustic Noise Effect from Class II MLCC Vibration

While dedicated “low acoustic noise MLCC” solutions can be found on the market, are there any other effective ways to address a smartphone’s MLCC-driven high-pitched humming noise issue before resorting to this expensive remedy?

System speeds across all platforms continue to escalate. It’s expected that a 5G smartphone will need more than 30% overall capacitance than a 4G equivalent—an increase that’s akin to what’s happening with other applications across the industry. As a result, multi-layer ceramic capacitors (MLCCs) have become more popular than ever in many types of designs.

With this unavoidable surge in MLCC usage, the acoustic noise effect of MLCCs has become more commonly seen recently. Especially for consumer devices such as laptops and cell phones, which are often used in quiet settings, the MLCC acoustic noise from these products gives the impression of poor product quality and thus is utterly unacceptable to end users. This article will present practical design strategies to circumvent this effect, as well as introduce some commercially available low acoustic MLCC solutions.

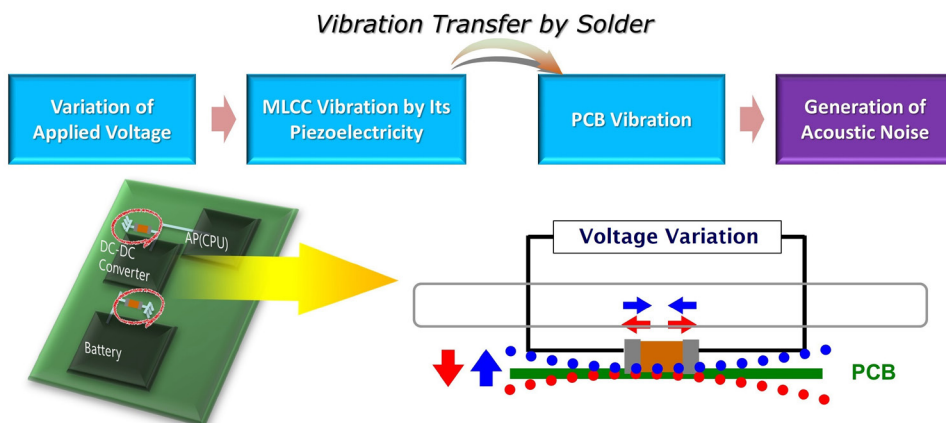
What Causes MLCC Acoustic Noise?

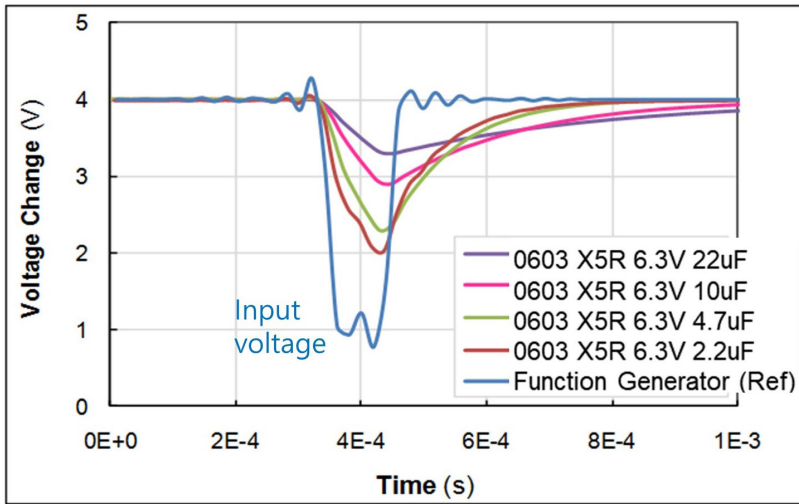
Before we dive into the solutions, let’s look into the origin of the problem. The MLCC acoustic noise effect is only observed in Class II MLCC (typically X5R, X6S, or X7* rated), where the dielectric material is usually made of barium titanate (BaTiO_3).

While BaTiO_3 enjoys the characteristic of high dielectric constant (k) to make small- and high-capacitance MLCC possible, it unfortunately also has a piezoelectric effect. (When BaTiO_3 is below the curie temperature of 125°C , the crystal structure of this material becomes tetragonal; spontaneous polarization of off-centered Ti-ion causes the piezoelectric effect of BaTiO_3 .)

As a result, when sinusoidal signals pass through this type of MLCC, the piezoelectric effect makes the MLCC start to vibrate. Such vibration is subsequently transferred to the PCB through the solder fillets at both terminals of

1. MLCCs used in a PCB’s power lines result in vibration, and “acoustic noise” may be heard when PCB vibration is within a human’s audible frequency range of 20 Hz to 20 kHz.





2. As the capacitance of an MLCC increases within the same case size, the voltage ripple drops, decreasing the acoustic noise level.

electric constant (k) of BaTiO_3 . In general, k is proportional to the intensity of the piezoelectric effect, so an MLCC with higher k is more prone to acoustic noise effect than that with lower k . However, the dielectric constant of a particular MLCC base material is typically not disclosed from MLCC suppliers. So, as a rule of thumb, larger case size MLCC parts (e.g., 3216 or 3225) usually have lower k materials than those of the same capacitance but in a smaller case size.

PCB

the MLCC. If the vibration's intensity is strong enough and happens to be within a human's audible frequency range of 20 Hz to 20 kHz, a humming "acoustic noise" can be heard (Fig. 1).

With an understanding of the mechanism of MLCC acoustic noise generation, we can now examine the three critical parts inside this problem: MLCC, PCB, and solder fillet.

The Three Acoustic-Noise Culprits MLCC

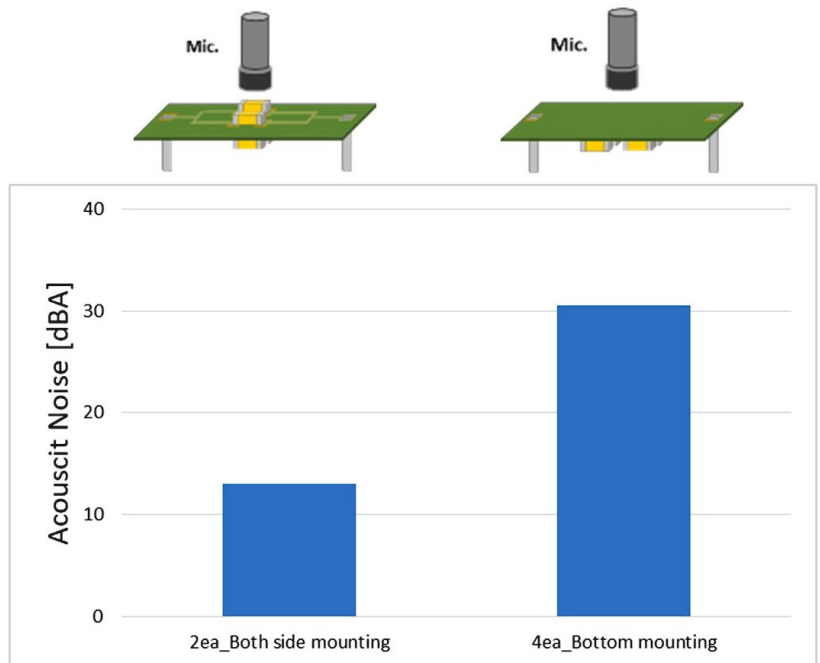
The acoustic noise generation at the capacitor level is determined by the structure and composition of the MLCC. If we compare two different MLCC parts with the same case size, the one with lower capacitance will have more acoustic noise (Fig. 2). The reason for this behavior is that higher capacitance reduces voltage ripple with time (dV/dt), and under piezoelectric effect, smaller dV/dt simply means smaller physical displacement, or smaller vibration intensity.

Thus, one potential way to reduce acoustic noise is to choose a higher-capacitance MLCC available within the same case size. By the same token, the capacitance decrease due to increased dc bias also increases dV/dt . So, for the same MLCC, operating at a lower dc bias or choosing a part with less dc bias effect is preferable for acoustic noise reduction.

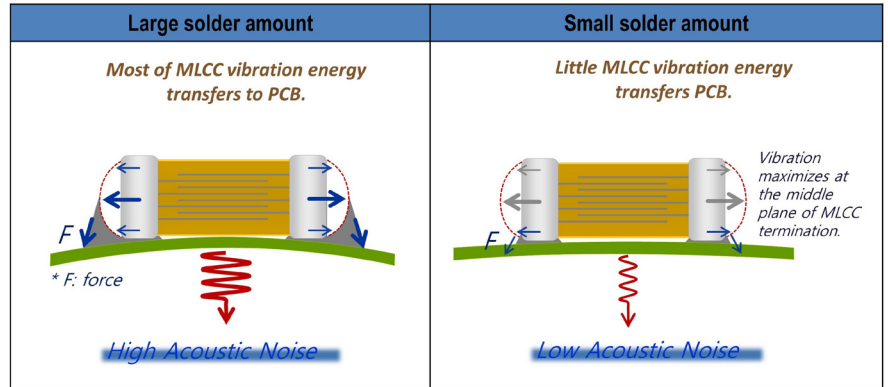
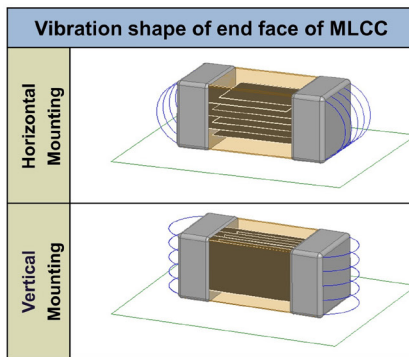
Another factor that also affects acoustic noise generation is the di-

A printed circuit board (PCB) plays an equally important part in acoustic noise generation. It's been found that the most effective noise-reducing PCB layout configuration is to mount the same type of MLCC at the same location on both sides of the PCB (Fig. 3). That's because the vibration mode from both sides essentially cancels out each other, thus reducing overall PCB vibration.

While the above suggestions are all valid methods for reducing the MLCC acoustic noise effect, sometimes they may not be as useful since certain design constraints will limit the choice of capacitance values or sizes. Furthermore, it's



3. Mounting MLCCs at the same location on both sides of the PCB reduces acoustic noise.



4. The vibration amplitude maximizes at the middle plane of MLCC's termination, horizontal to the dielectric layers.

not always possible to implement dual-side SMT in many designs. Fortunately, there are more effective and practical ways to help.

Solder Fillets

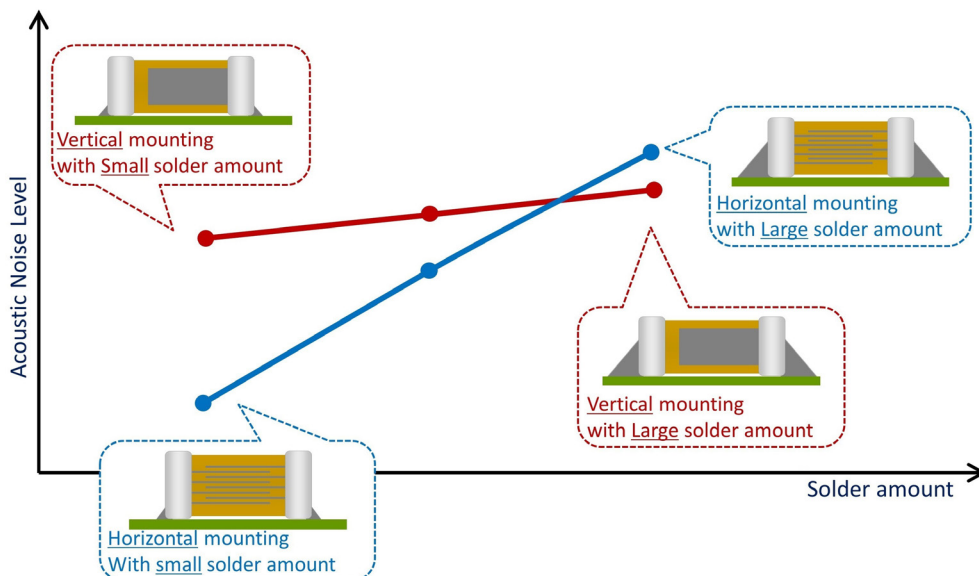
If we scan the deformation shape of an MLCC with a laser Doppler vibrometer when a capacitor is subject to a sinusoidal signal, the vibration amplitude maximizes at the middle plane of the MLCC's termination, horizontal to the dielectric layers (Fig. 4). The vibration energy is subsequently transferred to the PCB through the solder fillets at the terminations at both ends of the MLCC. So, if we're able to have the MLCC mount with the dielectric layers parallel to the PCB plane, aka "horizontal mounting," and at the same time apply a minimal amount of solder (Fig. 4, again), we've essentially eliminated the path of vibration energy transfer.

A horizontal-mounting MLCC is preferred because with a small solder-fillet design, it's possible to avoid most vibration energy being transferred to the PCB. However, with vertical-mounting MLCCs, there's no way to escape the vi-

bration plane with the highest vibration displacement. That's because that plane is always perpendicular to the solder fillet, no matter how small the solder fillet. Therefore, a horizontally mounted MLCC is preferred in terms of acoustic noise reduction.

While horizontally mounted MLCCs generally provide lower acoustic noise, it's nevertheless interesting to note that this isn't the case when there's a large amount of solder (Fig. 5). When the height of the solder fillet is higher than the termination's halfway point, a vertically mounted MLCC actually provides a lower acoustic noise effect. That's because when the solder fillet is higher than the termination's halfway point, most vibration displacement energy may be transferred to the PCB if the MLCC is mounted horizontally. Whereas in vertical mounting, a relatively smaller part of that energy is transferred.

At this point, we've learned that the most effective way of reducing the acoustic noise is by mounting the MLCC horizontally while applying a minimal amount of solder.



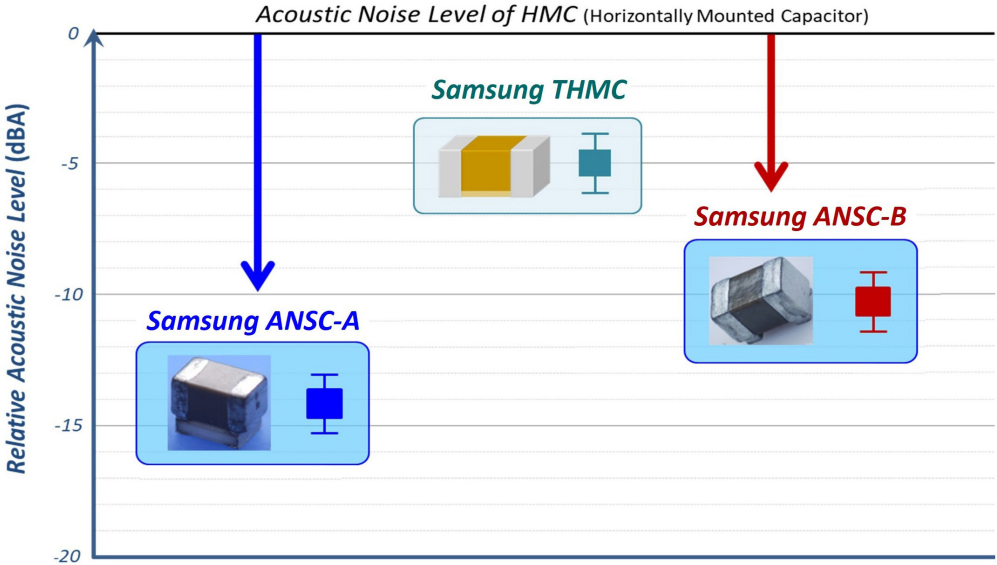
5. The configuration that yields the lowest acoustic noise is a horizontally mounted MLCC with a small solder fillet.

Currently, horizontally mounted MLCCs are available through MLCC suppliers by utilizing a special sorting process before tape-and-reel to ensure all MLCCs have the dielectric layers parallel to the PCB during SMT. (A general-purpose MLCC's orientation isn't controlled during the tape-and-reel process; in addition, it's impossible to tell the orientation of an MLCC from its appearance after tape-and-reel because the terminations have a square shape.) Applying a smaller solder fillet, on the other hand, is a much more challenging practice due to SMT technical capability limitations and potential reliability concerns.

A Specialized Option

What if all of the above-mentioned design tips fail to yield an acceptable outcome, or if design restrictions are in place that prevent engineers from using any of the strategies? Having learned about the origin and tricks for reducing acoustic noise, we can now introduce a specialized “low acoustic noise MLCC” to help with this issue.

The basic design concept for all low acoustic noise MLCCs is to minimize the vibration energy transfer to the

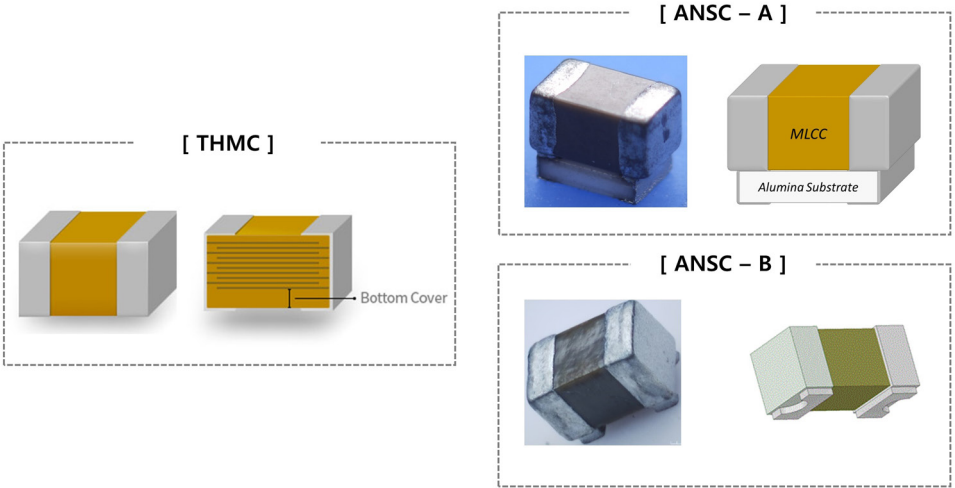


6. There are two different types of low acoustic noise MLCCs. The first has a thicker dielectric bottom layer (e.g., Samsung THMC series), while the second type has a separate physical structure underneath (e.g., Samsung ANSC-A or ANSC-B series). The ANSC-A series' separation structure is an alumina substrate, while the ANSC-B series' separation structure is a piece of metal plate attached to each termination.

PCB through the solder fillet. Since the highest vibration displacement takes place at the middle plane of the MLCC body, low acoustic MLCC parts simply add an additional physical structure underneath the “traditional” MLCC body—dielectric and metal layers—to elevate that plane and thus minimize such energy transfer through the solder fillet (Fig. 6).

Differentiated by the structure of that added physical structure, low acoustic MLCCs can normally be categorized into two types. The first type is to thicken the dielectric layer at the bottom of a typical capacitor body (e.g., Samsung's THMC series), while the other type is to attach a separate physical structure made of different material, such as an

7. The noise reduction performance of ANSC type of MLCC surpasses that of a THMC type.



alumina substrate (e.g., Samsung's ANSC-A series) or metal plate (e.g., Samsung's ANSC-B series) to a standard MLCC (Fig. 7).

Both of those designs significantly reduce the noise effect, but the performance of the second type is much superior to that of the first type. The reason is that the separate structure found in the second type can provide a much stronger isolation of vibration energy transfer. However, the disadvantage of the second type is that the added structure thickness would cause the MLCC to have more height than the first type (assuming MLCC electric spec is the same), and thus may be an issue for applications with height limitations.

In the real world, the most challenging part of dealing with MLCC acoustic noise during system design is that the effect could not be easily simulated in a straightforward way with software. That's because vibration patterns typically involve many interacting variables, such as PCB layout, physical system structure, and even the frequency or strength of the actual electrical signal.

Consequently, in most cases, MLCC acoustic noise issues aren't discovered until product verification or qualification stages, at which point there is usually very little time or flexibility for substantial design changes to be made. It will be very helpful if designers are familiar with all the noise reduction tips so that more options are on the table upon occurrence of the acoustic noise problem.

Conclusion

Before resorting to a low acoustic noise MLCC, some effective ways to help with the acoustic noise issue involve changing the MLCC to a higher capacitance part, reducing applied dc bias, using a horizontally mounted MLCC with small solder fillet, or, if possible, mounting an equivalent MLCC at the opposite side.

In cases where a low acoustic noise MLCC must be used, multiple choices are available in the market with different characteristics for different scenarios. A complete understanding of the MLCC acoustic noise effect will help designers cost-effectively mitigate this aggravating issue.

Herb Te-Jen Ma joined Samsung Electro-Mechanics Co. Ltd, or SEMCO, as an application engineer manager in October 2018. He received his MSEE and MSME from Stanford University in 2010. He has 10 years of experience in passive components, ICs, and Wi-Fi modules while working as a component and NPI engineer at Marvell Semiconductors.